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SIGNIFICANT ELECTRONIC APPLICATIONS AND EXPERIMENTAL RESULTS FROM PROJECT ECHO

NOVEMBER 1965

NASA

GODDARD SPACE FLIGHT CENTER
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NOVEMBER 1965

Presented by Members of the Echo II Project Staff, Goddard Space Flight Center, Greenbelt, Maryland at WESCON/65, San Francisco, August 24-27, 1965

Goddard Space Flight Center
Greenbelt, Maryland

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by H. L. Eaker, Goddard Space Flight Center

SUMMARY

The primary objective of Project Echo II, was to design, develop and demonstrate in orbit, a passive communication satellite that could maintain its spherical shape and smooth surface characteristics in a space environment, even after the loss of its internal inflatant pressure. Demonstration of the satellite's performance was to be accomplished by means of extensive satellite experiments involving tests in the area of communications, radar and optics.

Extensive tests were conducted on satellite prototypes prior to fabrication of the flight article. Their large size (135 feet in diameter) presented special problems in conducting the tests. Inflation tests were conducted in a dirigible hangar at the Naval Air Station, Lakehurst, New Jersey, for the purpose of evaluating the structural, and RF backscattering characteristics of the sphere as a function of its internal pressure.

Vertical ballistic tests were conducted at the Eastern Test Range in order that the satellite deployment and inflation technique could be properly evaluated prior to the orbital launch. The unique application of a television system designed to observe and record spacecraft operation was employed in the vertical tests as well as on the orbital launch.

The Echo II satellite was launched from the Western Test Range on January 25, 1964. Extensive communication experiments were conducted via the satellite throughout 1964. These experiments were conducted using facilities of the Naval Research Laboratory, Washington, D.C., Collins Radio Company, Dallas, Texas, and the Ohio State University, Columbus, Ohio. The primary objective of the experiments was to determine the passive communications capability of the satellite, and in conjunction with radar experiments, to provide information about the shape and surface characteristics of the satellite as a function of time. Excellent results were obtained from these experiments and it can be concluded that the Echo II

satellite provides a very satisfactory reflector for use in passive communications systems. Limited experiments were also conducted via the Echo I satellite. While the results indicate Echo II is superior to Echo I as a communication satellite, they also indicate that Echo I still provides a very useful communications medium.

INTRODUCTION

Project Echo II represents a second step in the National Aeronautics and Space Administration's (NASA) development of large spherical satellites for use as reflectors of radio frequency signals. The first step, Echo I, successfully confirmed the feasibility of launching a large space inflatable sphere into orbit; confirmed the predictions of propagation theory regarding the reflection of electromagnetic waves from such satellites; provided information about the effects of space environment on large orbiting spheres; and demonstrated the feasibility of communications via such satellites.

Echo I was launched August 12, 1960 from the Eastern Test Range in Florida. The 100-foot-diameter satellite weighed approximately 135 pounds, and was constructed of 0.5 mil Mylar with a vapor deposited aluminum coating to provide an RF reflective surface.

Communications experiments conducted during the early lifetime of Echo I indicated that its original spherical shape and smooth surface began to deteriorate within two weeks after launch, causing an increasing range of amplitude fluctuation (fading) of the reflected signals. The satellite is still in orbit and in spite of this apparent surface condition, continues to be quite effective as a passive communication satellite.

PROJECT OBJECTIVES

Although Echo I was most successful in achieving its established objectives, the early degradation in the performance of the sphere as a communication satellite pointed out the need for a passive satellite which could maintain desirable RF reflectivity characteristics over a longer period of time. Project Echo II was established for this purpose.

The primary objective of Echo II, therefore, was to design, develop and demonstrate in orbit, a passive communication satellite that could maintain its spherical shape and smooth surface characteristics in a space environment, even after the loss of its internal inflatant pressure. Demonstration of the satellite's performance was to be accomplished by means of extensive satellite experiments involving tests in the area of communications, radar and optics.

PROGRAM IMPLEMENTATION

General

Work began on the Echo II project during the early part of 1961. The project plan involved the following major phases:

- Spacecraft Design and Development
- Spacecraft Testing
- Orbital Launch
- Satellite Experiments

SPACECRAFT DESIGN AND DEVELOPMENT

Early in the Echo II program the decision was made to utilize the Echo I type of spacecraft system. The satellite was to be spherical in shape with a diameter of approximately 135 feet. It would be an inflatable structure constructed from a three layer aluminum foil-mylar laminate to provide the desired rigidity characteristic. Figure 1 illustrates the type of material used in the construction of the two Echo satellites.

The 135 foot diameter Echo II sphere was fabricated from 106 gores, each 48 inches wide at the equator. The gores were joined by simple butt splicing

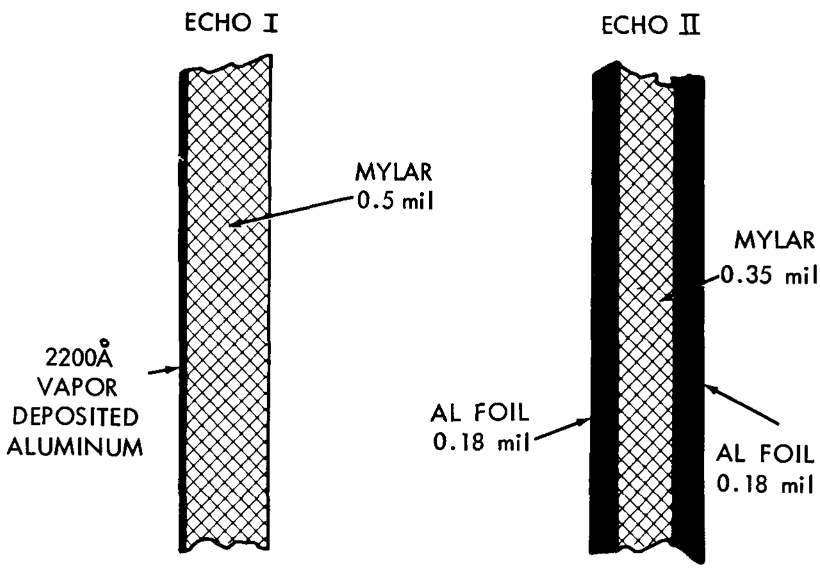


Figure 1. Cross-Sections of Echo I and Echo II Material

with 1 inch wide tape of the sphere material coated with a thermosetting adhesive, terminating at the polar areas of the sphere where 54 inch diameter pole caps were attached using a 1 inch overlapping joint.

Two radio telemetry beacons[1] were mounted diametrically opposite one another at the sphere's equator. These beacons served as a tracking aid and also transmitted data on satellite temperature and pressure. The areas of the sphere near the beacons were reinforced with additional layers of Mylar film to preclude damage to the sphere as a result of forces experienced during deployment. Figure 2 is a photograph of the beacon system being installed on the structure by Goddard engineers.

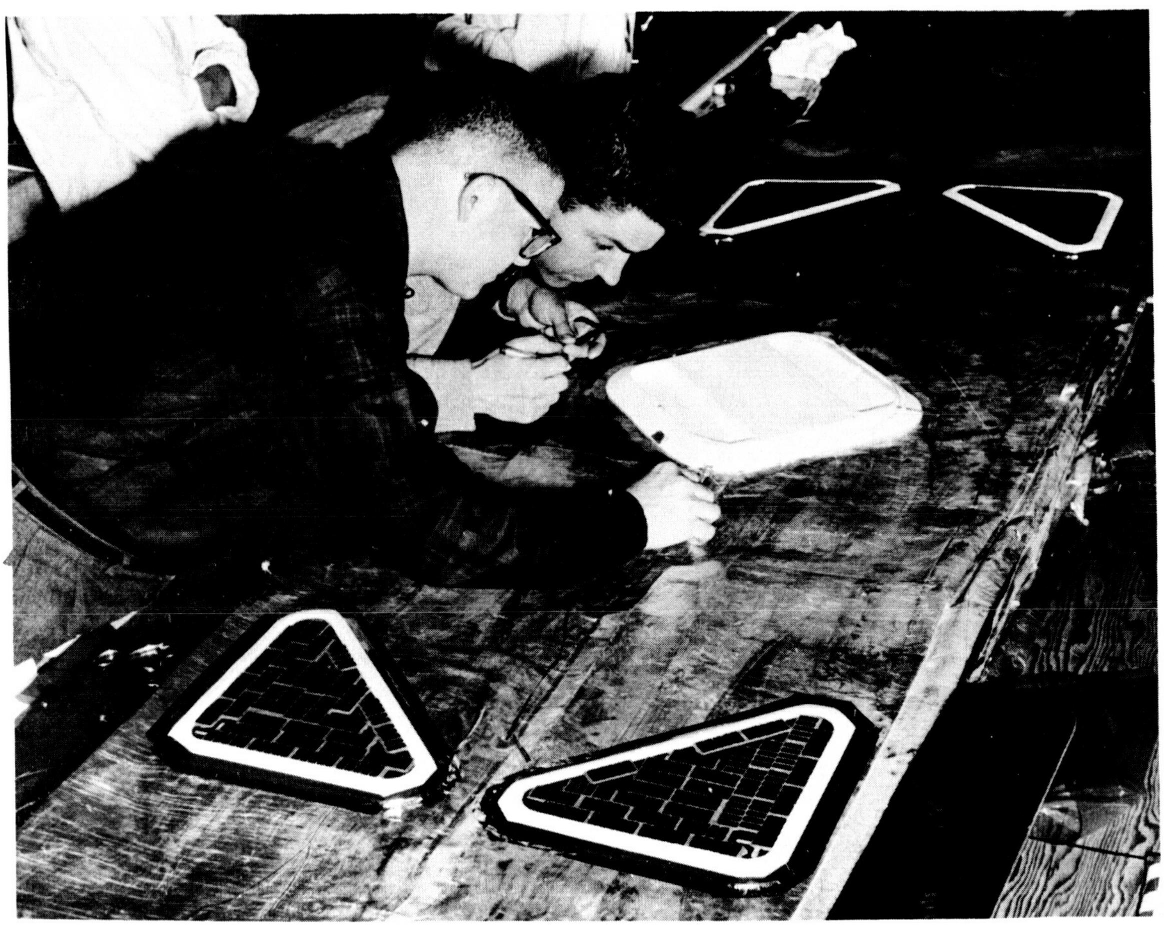


Figure 2. Installation of Echo II Beacon System

The structure was folded and packed in its container (canister) as indicated in Figure 3. The container as well as the satellite itself is then evacuated, to prevent excessively rapid inflation of the satellite by expansion of residual air inside the satellite.

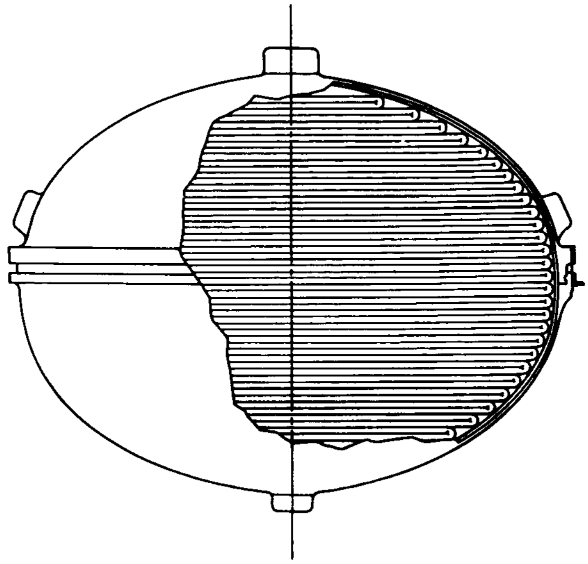


Figure 3. Echo II Satellite Folded in Container

The spacecraft, consisting of the container and its adapter as pictured in Figure 4 was then mounted on the launch vehicle by means of which it was launched into orbit.

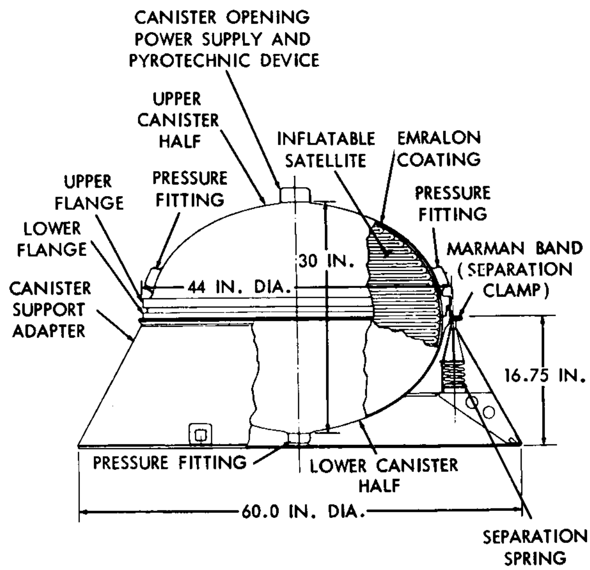


Figure 4. Echo II Spacecraft

The operational sequence of the spacecraft operation is illustrated in Figure 5. After reaching the desired altitude (a), the canister was ejected from the launch vehicle (b), and after a predetermined time delay, the two halves of the canister were separated by means of an explosive shaped charge placed around the equator of the canister (c). When the two halves of the container were separated, residual air within the folded satellite expanded and partially inflated the sphere (c). Continued inflation and full pressurization of the sphere (d) was accomplished by means of the inflatant gas provided by a subliming compound placed in the sphere during its fabrication and prior to installation in its container.

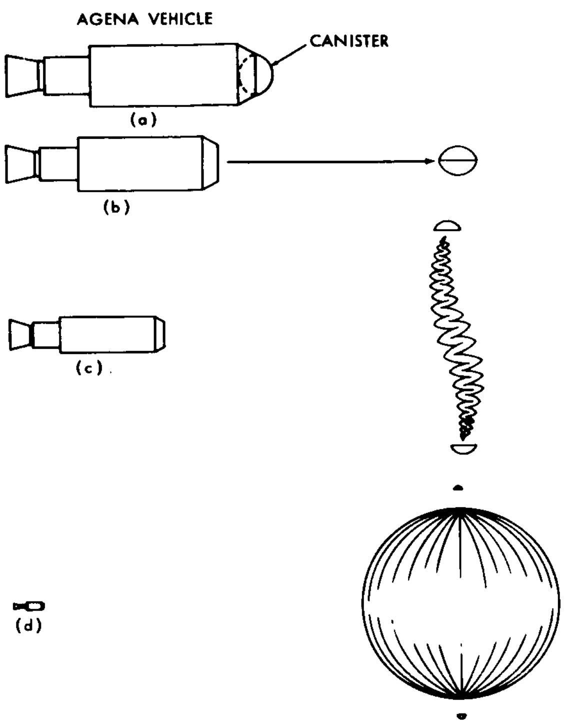


Figure 5. Operational Sequence of Echo II Spacecraft

SPACECRAFT TESTING

General

Testing of the Echo spacecraft presented some rather interesting and unique problems, particularly in the area of obtaining adequately sized ground test facilities. Because of its large size, the 135 foot structure was not adaptable to existing environmental test facilities. Therefore, special facilities and techniques were necessary.

Testing of the spacecraft was accomplished in three ways.

- Laboratory tests

- Static Inflation tests

- Vertical tests

LABORATORY TESTING

The first, laboratory tests, were accomplished by using conventional environmental test facilities for testing such items as the basic satellite material, canister operation, and satellite unfolding sequences. Figure 6 demonstrates one of the methods used in testing the canister operation, and satellite unfolding sequence.

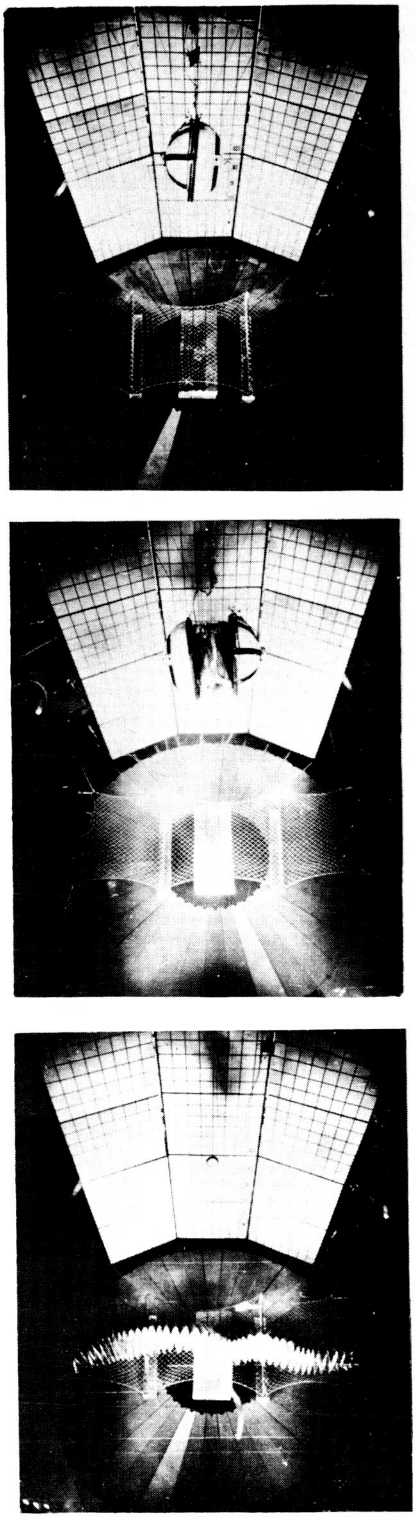


Figure 6. Echo II Vacuum Tank Test

These tests were conducted in one of Goddard's large vacuum tanks in which the canister with the test sphere packed inside was suspended from the top of the tank as indicated at the top of Figure 6. Immediately after the canister was released, canister opening was initiated (center picture), thus permitting the sphere to deploy as it dropped to the bottom of the tank. The lower picture shows the sphere just as it reached the bottom of the tank.

Although the test time was only about 1 second, verification of certain initial spacecraft operational sequences in a simulated space environment was achieved.

STATIC INFLATION TESTING

Because of its very large area to mass ratio, it was necessary that the fully inflated test spheres be housed within some large protective structure for full scale tests. The large hangar (formerly used for lighter than air balloons) at the Naval Air Station, Lakehurst, New Jersey were selected for these tests.[2] The major objective of the tests were:

- To evaluate rf backscatter characteristics of the test sphere as a function of internal pressure;

- To evaluate the structural characteristics of test spheres as a functional of internal pressure.

Radar back scatter measurements were conducted on the structure; the spherical surface of the spheres were studied by means of photogrammetric techniques as well as by means of mechanical templates; and extensive photography of the spheres surface was made during the various stages of the test. Figure 7 illustrates the test arrangement used in the hangar for testing the spheres. Figure 8 is one of the many photographs taken by Goddard photographers at the test and illustrates rather dramatically the test arrangement shown in Figure 7.

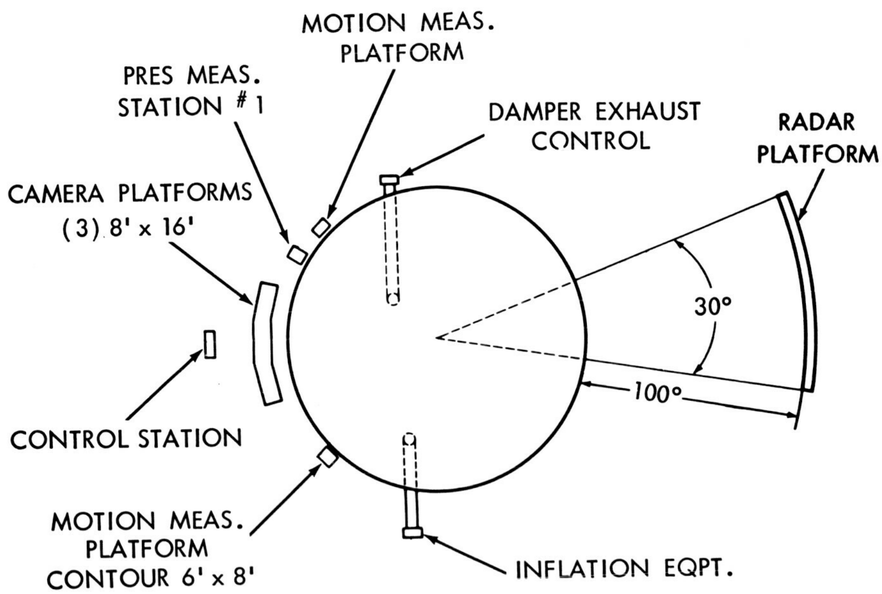


Figure 7. Echo II Static Inflation Test Arrangement

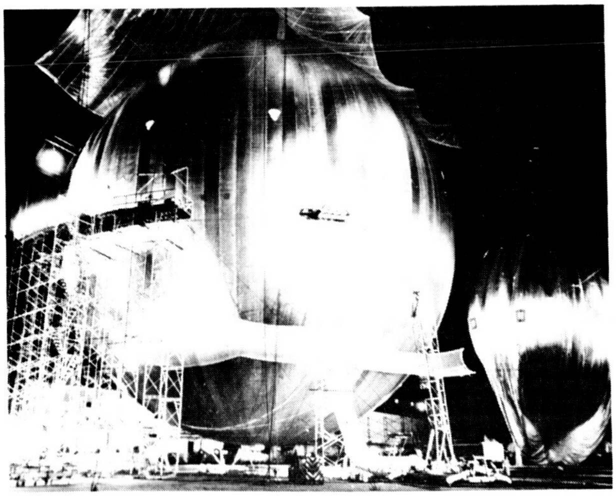


Figure 8. Echo II Test Spheres

Figure 9 illustrates some of the results of the rf backscatter measurements conducted on the test spheres. The top curve shows the signal return recorded at the initial sphere skin stress of approximately 400 psi. The lower curve indicates the returned signal, also at 400 psi but with one significant difference — after the balloon had been stressed to 7400 psi and then relaxed to the 400 psi level. The return from the latter condition (after the higher skin stress) is obviously smoother than the first pre-stressed low pressure condition.

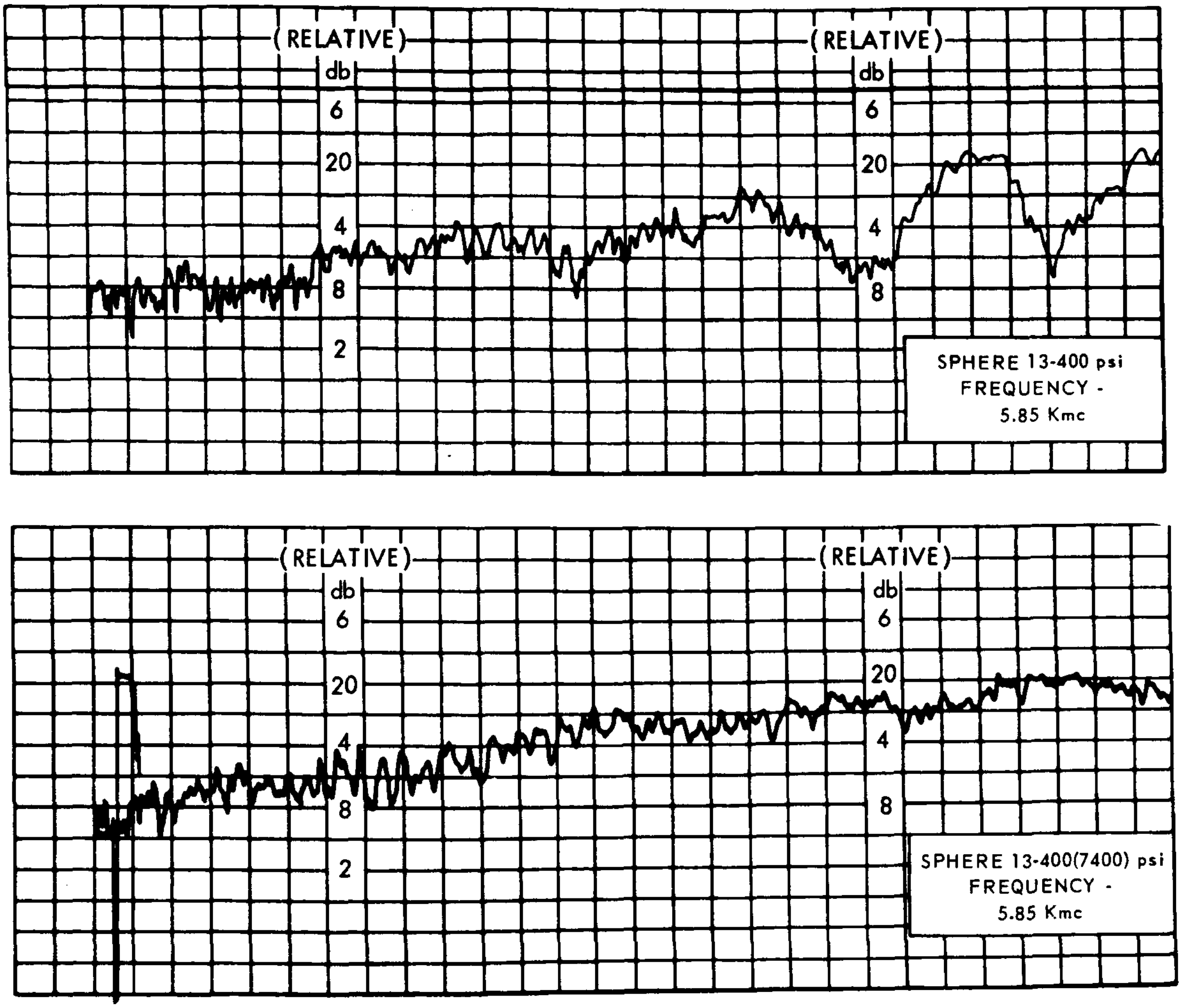


Figure 9. Signal Traces of Back Scatter Measurement on Echo II Test Sphere

The results of the Static Inflation Test verified that once the series of flat gores from which the sphere is constructed are stressed above a certain level, the structure attains a more spherical shape, and tends to retain that shape, even after the internal pressure is removed. This is necessary if the structure is to attain the desired rigidity characteristics.

It was also determined during these tests that orbital prototype spheres could withstand internal pressures corresponding to surface skin stress of approximately 18,000 psi. This provided a safety factor in excess of four over the skin stress required to achieve the desired surface smoothness and rigidity characteristics referred to above.

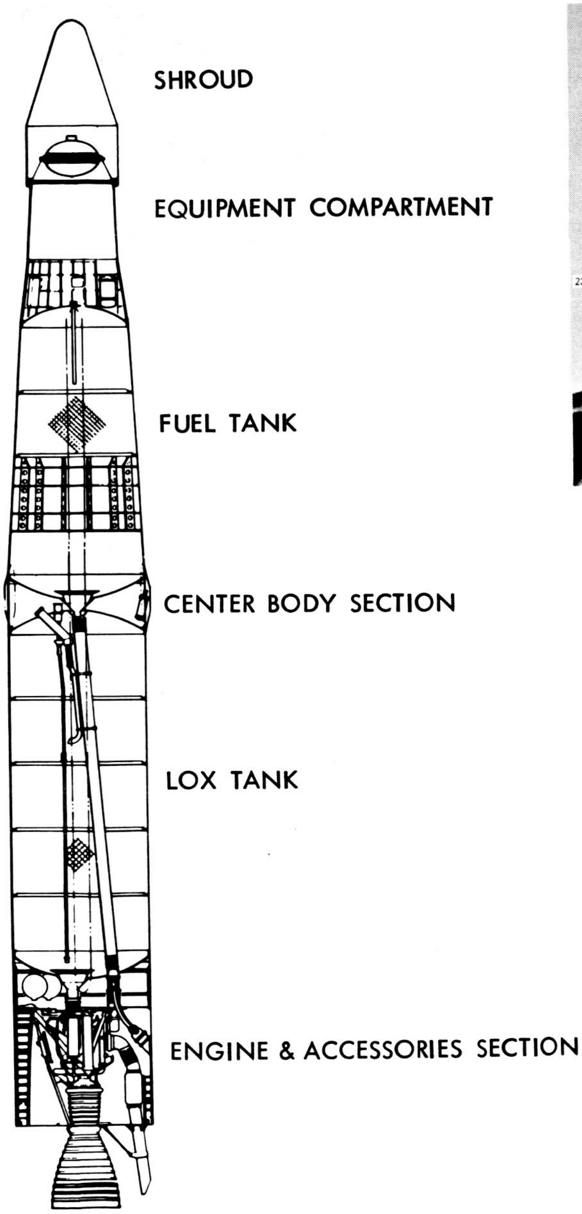
VERTICAL TESTING

In order to be better assured of a satisfactory orbital launch, it was necessary that the Echo II spacecraft prototype be properly qualified in a space environment. Because of the large area required to conduct such tests, it was necessary to launch the sphere into a ballistic type trajectory such that spacecraft operation would take place in what was essentially a space environment. Two such tests were conducted at Cape Kennedy - the first, in January 1962 and the second in July 1962.

Since the prime objective of these tests was to evaluate the operation of the spacecraft, it was essential that such operation be closely observed. A complication to the problem was the fact that spacecraft operation took place at an altitude such that proper visual observation of spacecraft performance was impossible with existing ground equipment. It was therefore necessary to provide a means of visually observing the operation at a much closer range. This was accomplished by means of a specially instrumented launch vehicle.

The THOR rocket was selected as the launch vehicle for this purpose. The basic vehicle was modified so that it could follow the test sphere during most of its ballistic trajectory, maintaining a position such that both a film camera and a television camera[3] mounted in the forward section of the vehicle, could photograph and observe spacecraft performance. Figure 10 is a sketch of the test vehicle with spacecraft and protective shroud. The equipment compartment contains (among other things) the television system and a 16 mm movie camera, used for observing spacecraft operations.

The major operational sequences involved in these vertical tests are illustrated in Figure 11. The vehicle was launched from Cape Kennedy, Florida. At an altitude of approximately 200 miles, the canister was ejected from the vehicle. About 20 seconds later the canister opened, immediately followed by deployment and initial inflation of the test sphere. Both the TV camera and the movie camera observed canister separation, sphere deployment and inflation. A TV receiving station at the Cape received and recorded the TV picture as transmitted from the vehicle. The data capsule which contained the movie camera was ejected from the launch vehicle down range from the Cape at an altitude of approxmately 200 miles. At the impact point, some 500 miles down range, the package containing the camera was recovered by a surface vessel stationed there for that purpose. The camera film was then returned to Cape Kennedy for reduction and analysis.



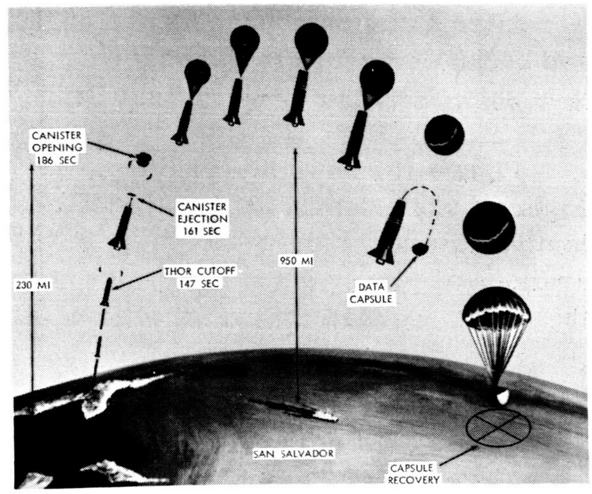


Figure 11. Operational Sequence of Echo II Vertical Tests

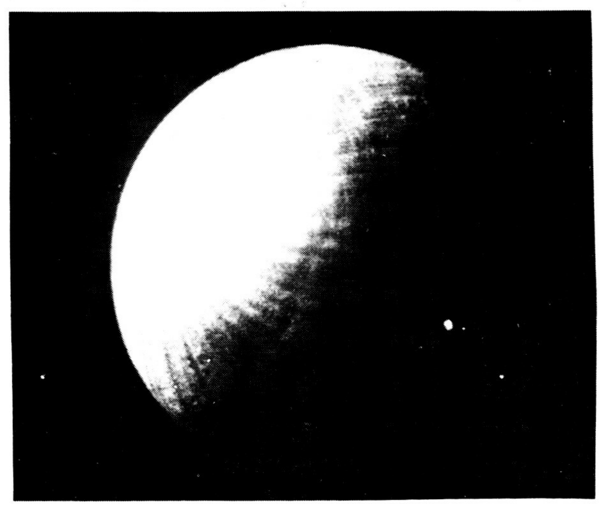


Figure 10. Echo II Vertical Test Vehicle

Figure 12. Echo II Vertical Test Sphere

Figure 12 is a photograph reproduced from the above data of the inflated test sphere used during the second vertical test. These tests were quite successful and provided valuable information regarding the operational performance of the spacecraft in preparation for the orbital launch.

ORBITAL LAUNCH

After satisfactory completion of the Echo II test program, the orbital prime and backup spacecrafts were fabricated and assembled. The two spacecrafts were then shipped to the Western Test Range in preparation for the orbital launch.

Figure 13 shows the spacecraft ready for mounting atop the launch vehicle. Figure 14 is a sketch illustrating the Agena vehicle with the spacecraft and protective shroud. Figure 15 is a picture of the orbital launch vehicle as final preparations are being made for launch at the Western Test Range. Figure 16 illustrates the major sequence of events planned for placing the satellite into orbit.

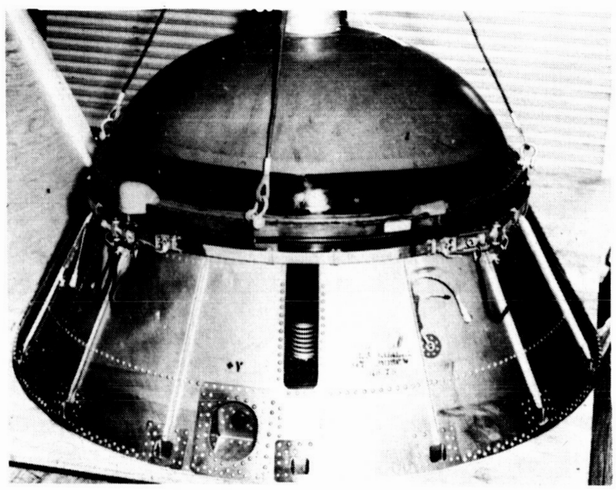


Figure 13. Echo II Spacecraft

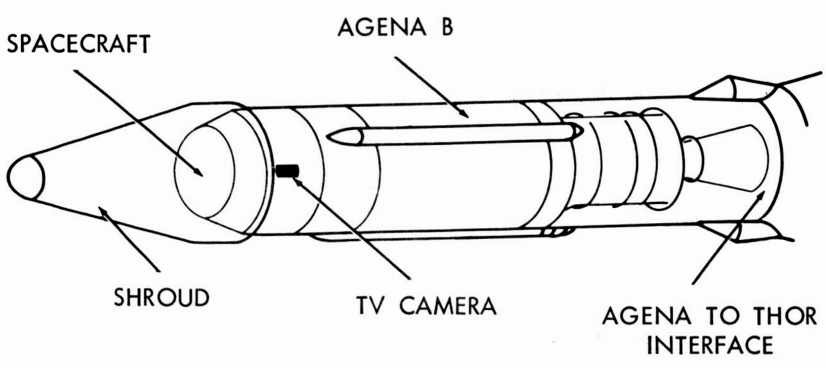


Figure 14. Agena Vehicle with Echo II Spacecraft

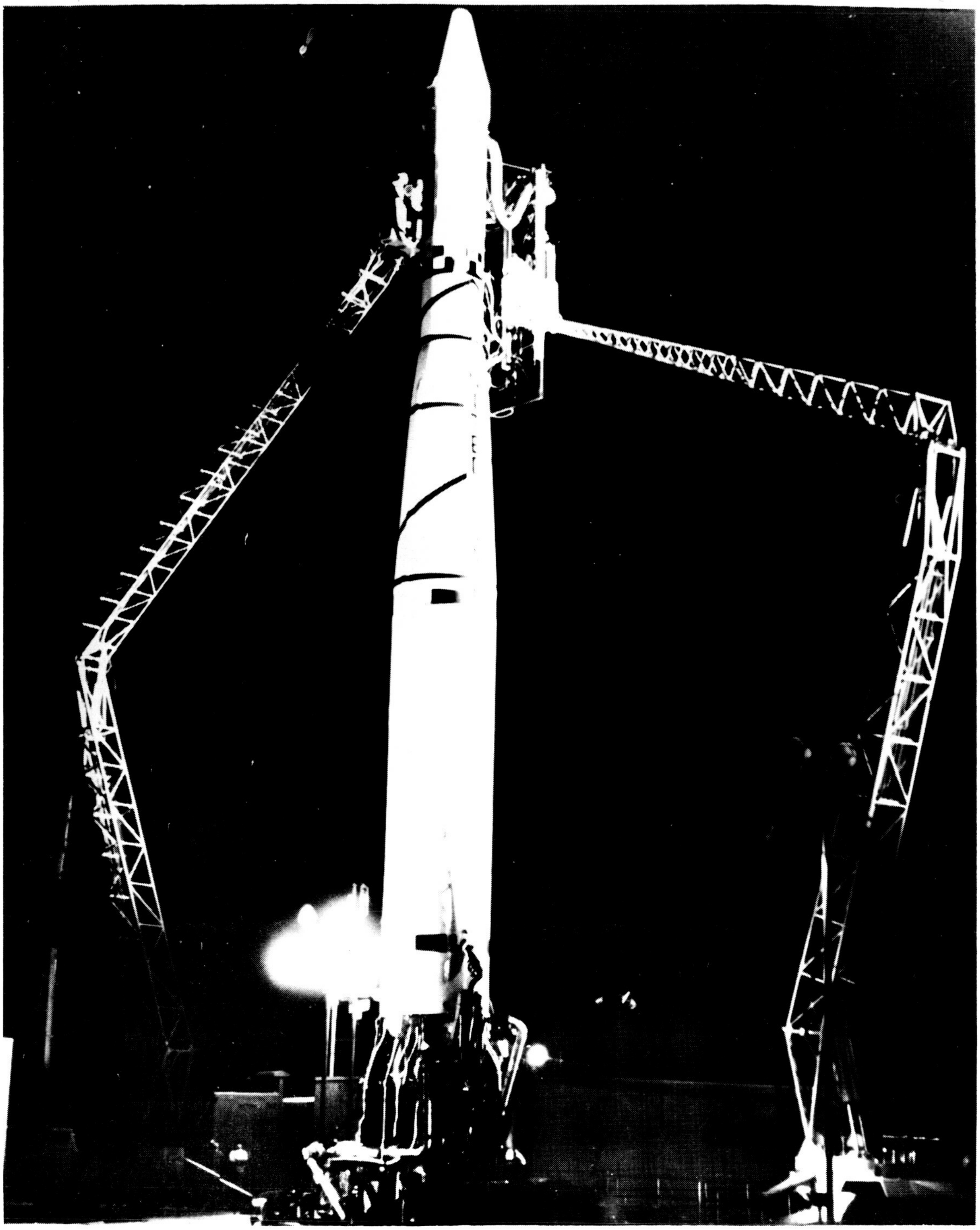


Figure 15. Echo II Orbital Launch Vehicle

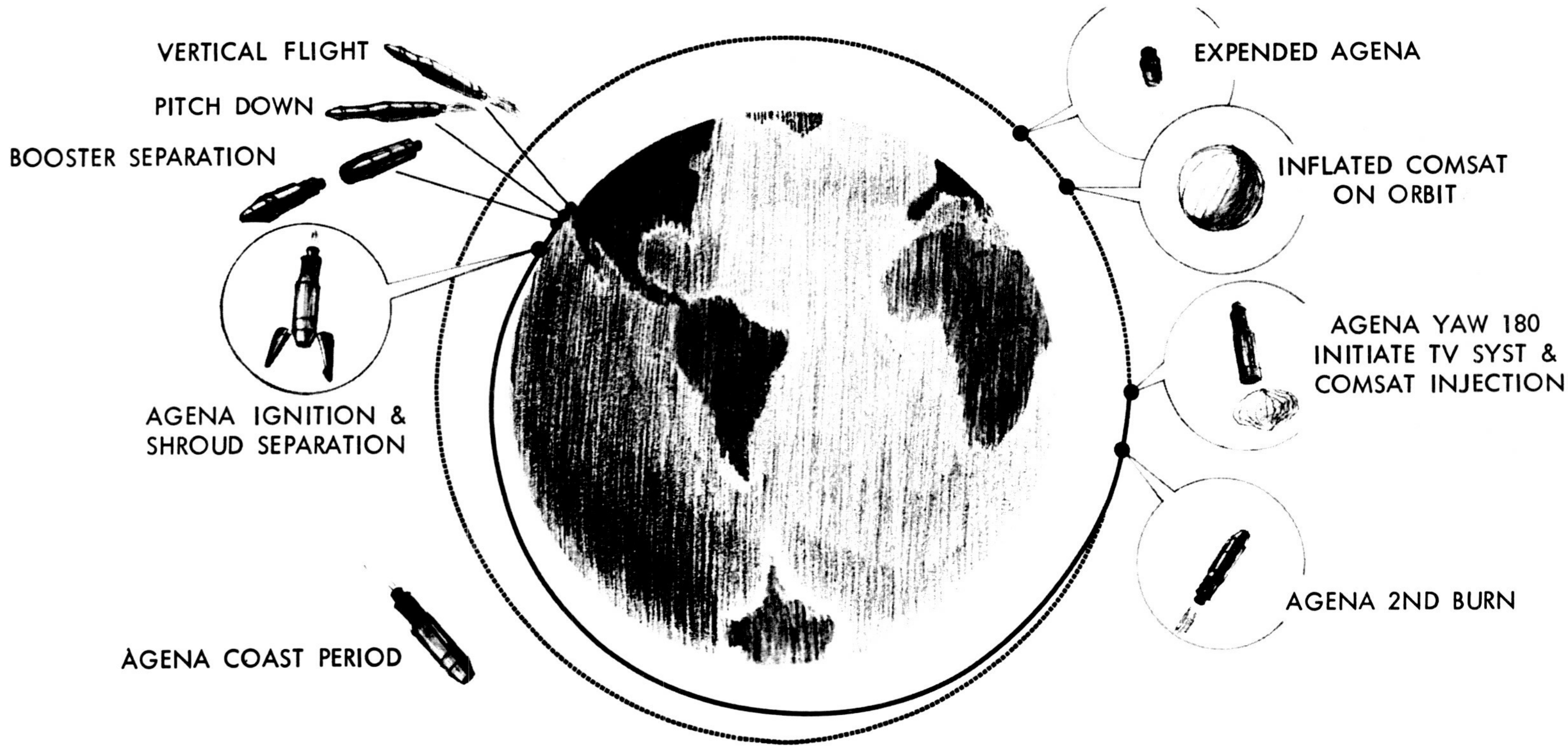


Figure 16. Echo II Orbital Launch Sequence

The Echo II satellite was launched on January 25th, 1964 at 0559 Pacific time. Approximately one hour after lift-off, the satellite was injected into orbit just south of Madagascar. The first few significant orbits of the satellite are shown in Figure 17.

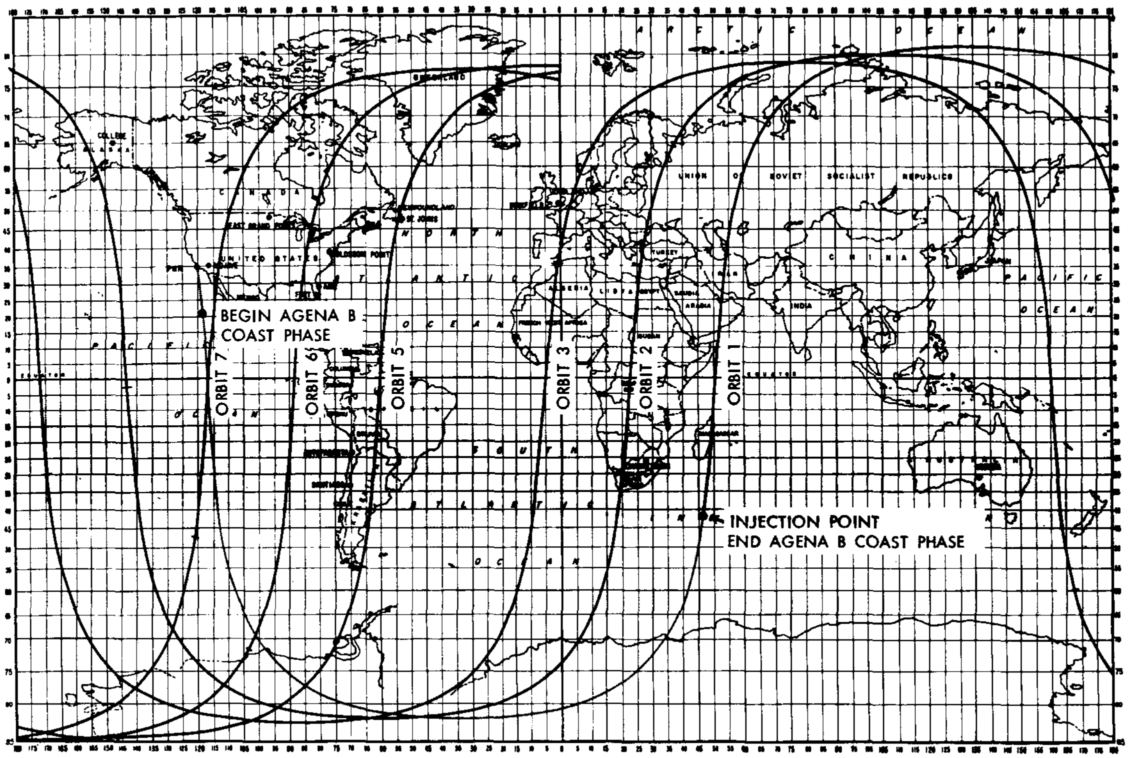


Figure 17. Sub-Orbital Plots of Echo II Satellite

The same television system so successfully employed in the vertical tests was also used with the orbital launch. The television transmitter system was installed in the Agena vehicle as indicated in Figure 18.

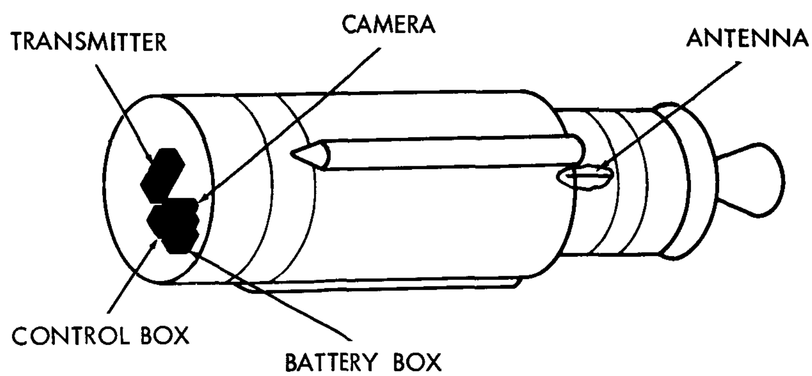


Figure 18. Echo II TV Installation in Agena Vehicle

A Goddard manned TV receiving station in South Africa received and recorded pictures of spacecraft operation as transmitted from the vehicle, including the unfolding and initial inflation of the satellite. This dramatic event is demonstrated in a motion picture film made from the recorded video tape. The sequence of pictures shown in Figure 19 was made from the video tape and illustrates the operation of the spacecraft as it is being injected into orbit (Refer to Fig. 5 also). These were the first pictures ever made of a satellite being injected into orbit.

A Goddard portable telemetry station at the northern tip of Madagascar received and recorded telemetry data concerning satellite temperature and pressure from radio telemetry beacons mounted on the equator of the satellite. Immediately upon completion of the first pass, the station noted that the satellite was spinning with a period of approximately 100 seconds. Not only was this unexpected, it was most undesirable. Such a spin rate established centrifugal forces within the satellite shell causing the surface to become somewhat wrinkled, which when combined with such a spin rate caused unexpectedly high fluctuations in the reflected RF signal, particularly at the higher frequencies. A Post Launch Analysis Report[4] describing in detail an account of satellite performance will be included in the Project Final Report. Details regarding the cause and nature of this satellite spin are included in the report.

Prior to launch of the satellite, a Communications Experiment Plan[5] had been carefully prepared for conducting experiments with the satellite. The primary objectives of these experiments were:

- To evaluate the spherical shape and surface characteristics of the satellite as a function of time;

- To determine the passive communications capability of the satellite.

These objectives were to be achieved by means of the following test program:

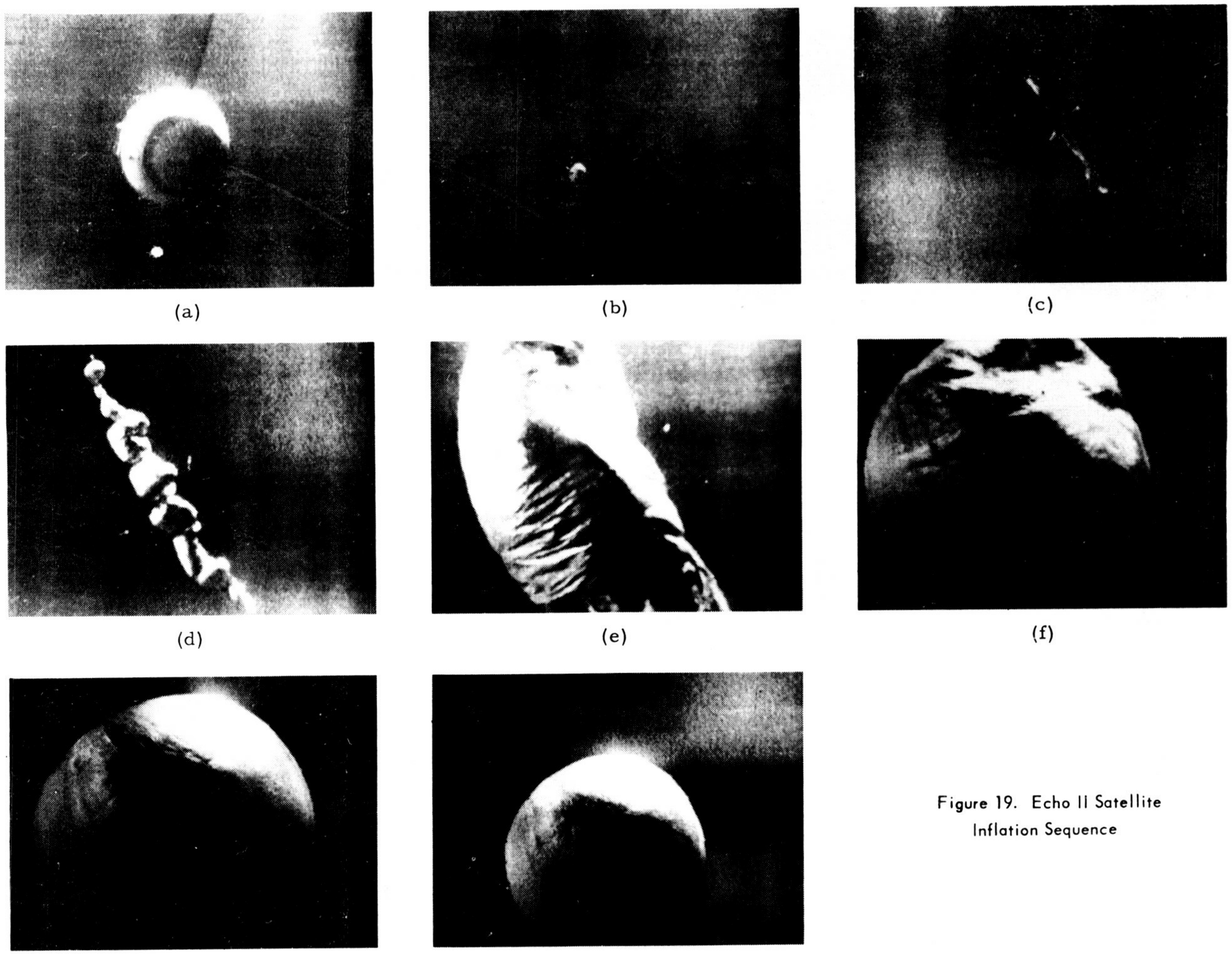
- Communications experiments

- Radar experiment

- Optics experiments

From the suborbital plots shown in Figure 17, the location of certain sites used in the experiment program can be located.

Observations of the satellite have been made over a wide RF frequency spectrum from uhf to X-band and on a timely periodic basis, since launch. This data, along with certain data collected from the optics stations at the Eastern Test Range and Wallops Island, Va., have provided an insight into the physical shape and surface characteristics of the satellite as well as its capabilities as a passive communications satellite.[6]



(a) (b) (c)

(d) (e) (f)

(g) (h)

Figure 19. Echo II Satellite Inflation Sequence

The following papers, presented by members of the Echo team, describe in detail some of the results of our Spacecraft Testing and Satellite Experimentation program. A summary of the overall project results is also included.

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6. Nyberg, W., "Result of Communication Experiment Conducted with the Echo II Satellite," GSFC, NASA, Greenbelt, Md.

G65-10066

FULL SCALE GROUND TESTS OF ECHO II PROTOTYPE SPHERES

by James P. Talentino, Goddard Space Flight Center

SUMMARY

One of the major problems involved in the Echo II program was the testing of the huge 135 foot diameter prototype spheres. Because of their large size, conventional test facilities were not readily adaptable for the spheres. As a result, full scale ground tests (Static Inflation Tests) were conducted on the spheres in the protected environment of dirigible hangars at the Naval Air Stations, Weeksville, North Carolina, and Lakehurst, New Jersey. The purpose of these ground inflation tests was to evaluate the structural and RF backscatter characteristics of Echo II test spheres as a function of their internal pressure.

Problems of testing included site selection, environmental effects, inflation techniques and methods of determining RF and structural properties. Environmental conditions and their effects on the sphere tests were studied. Meteorological parameters had various degrees of influence on the sphere stability which were either counteracted or taken into account in the data reduction.

RF backscatter measurements were conducted at L-band and C-band over a 30 degree section of the spheres. The measurements indicated that the scintillation levels improved as the internal pressure was increased (and then relaxed) approaching the design levels in the frequency bands tested. Photogrammetric contour and profile measurements and skin texture data did not yield adequate information for absolute determination of the sphere shape as a function of pressure. However, a qualitative evaluation indicated an improvement in the overall shape and skin texture. Despite premature failure in three of the four test spheres, in one case due to material defects and in two cases due to test appendage stress areas, the ultimate strength was demonstrated to be excellent in the flight quality sphere.

INTRODUCTION

As part of the Echo II testing program, several pre-orbital tests were made using full scale spheres. In May 1961 an inflation test was performed in a dirigible hangar at the Naval Air Station, Weeksville, North Carolina to determine general shape and burst pressure. Two sub-orbital flights were conducted in January and July 1962 to evaluate satellite system performance in the space environment. In the first flight the sphere ruptured during the deployment phase due to an excessively rapid inflation. In the second flight test, using a different inflatant, the sphere deployed satisfactorily but was not pressurized sufficiently to provide a good reflecting surface. As a result of the sub-orbital tests it was concluded that a thorough evaluation of the inflation characteristics was necessary by means of full scale ground tests.

The Goddard Space Flight Center conducted a series of full scale ground inflation tests of 135 foot diameter Echo II prototype spheres in June, July and December 1963. The purpose of these tests was to evaluate the structural and RF backscattering characteristics of Echo II as a function of internal pressure, and thus to establish the pressure required to achieve optimum reflecting characteristics.

The problem associated with testing such a large object included selection of a test site to accommodate the structure and test equipment, effect of the prevailing environment, methods of sphere inflation and pressure control, and methods of determining the RF, structural and physical characteristics.

It was proposed to perform the tests in a large lighter-than-air balloon hangar and to conduct RF backscatter measurements on the sphere concurrently with studies of the sphere surface by means of photogrammetric techniques, electromechanical devices, and photography.

EXPERIMENT PLAN AND RESULTS

Test Site

The selection of the test site was based on the physical size of the sphere, the prevalent environmental conditions which could affect the stability of the sphere, and the rather extensive logistics required for the support of such tests. Various types of sites were considered with the final choice being the dirigible hangar at the Naval Air Station, Lakehurst, New Jersey. This hangar had available clear space 800 feet long, 258 feet wide, and 172 feet high.

Test Arrangement

The general arrangement for the sphere inflation and test equipment is shown in Figures 1, 2, and 3. The sphere was located on the centerline of the hangar and held in position by twelve tie down lines. The equipment and scaffolding was arranged around the sphere at the appropriate distances. An inflation duct was attached to the spheres as shown in Figure 3. Air was exhausted from the spheres through the main exhaust duct and in emergencies, warm air was exhausted through the crown exhaust duct. The base exhaust duct permitted insertion of a lenticular balloon to aid in the erection of the spheres. Alternate gores of the spheres were numbered for the purposes of identifying and coordinating test results. A master control console was set up for maintaining control of pressure and other associated instruments. Over-pressurization of the spheres was indicated by an alarm system which was operated by a pressure switch. The corrective action was to completely close the inflation damper.

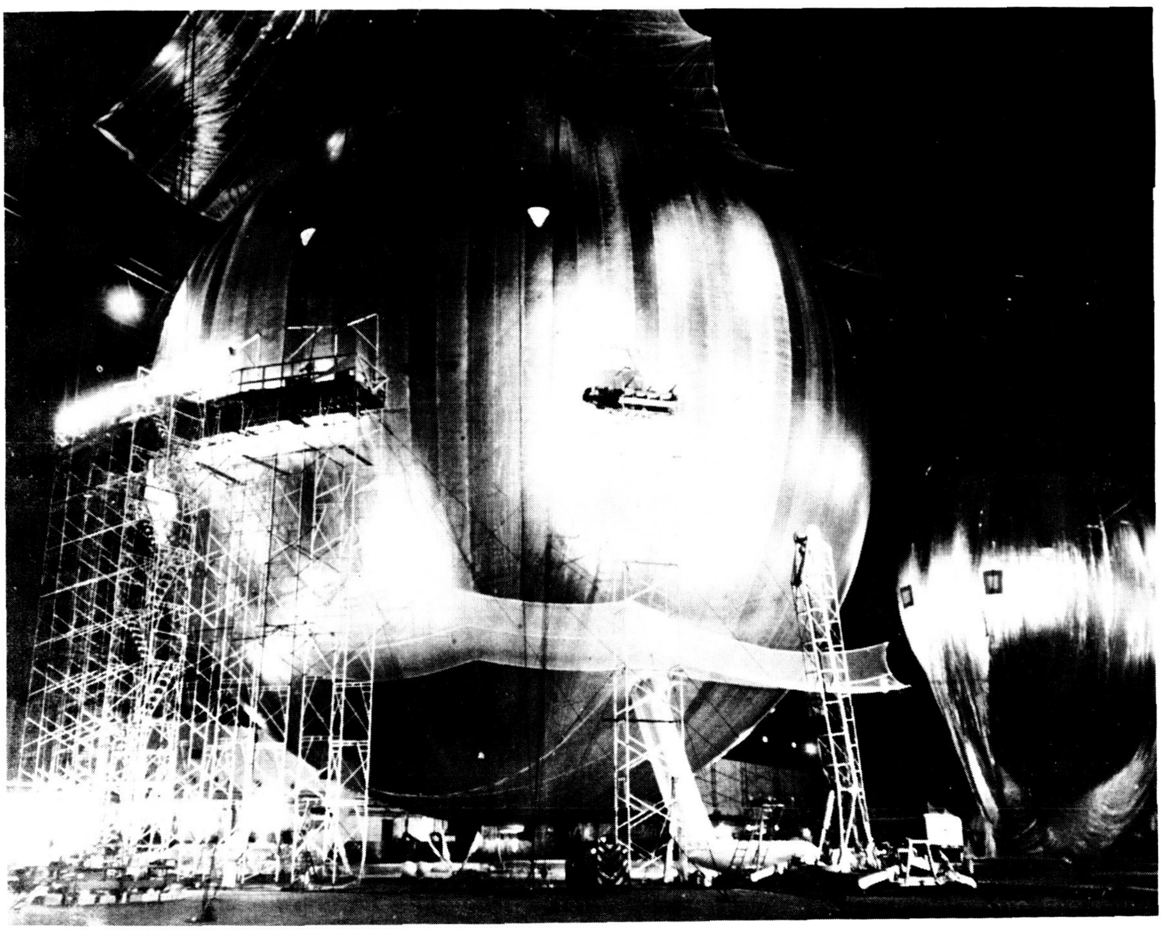


Figure 1. Echo II Ground Inflation Test

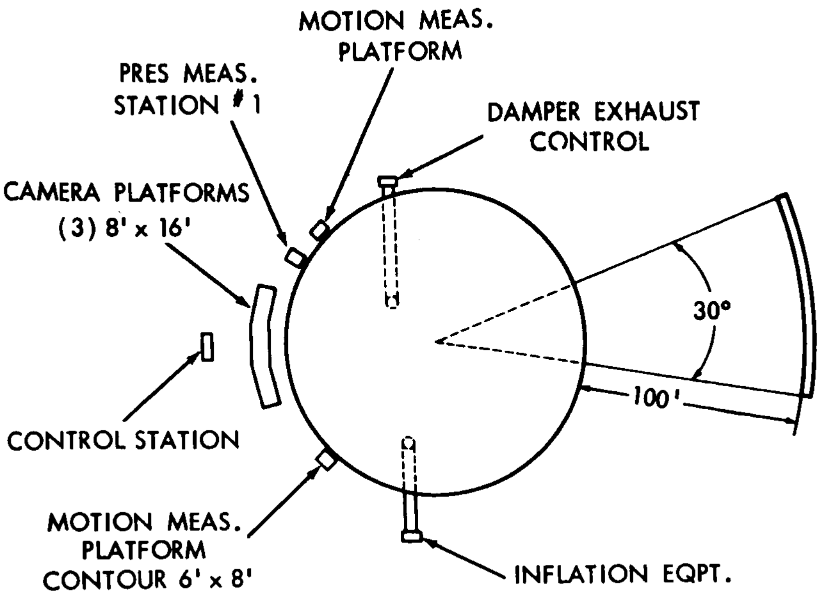


Figure 2. General Test Arrangement

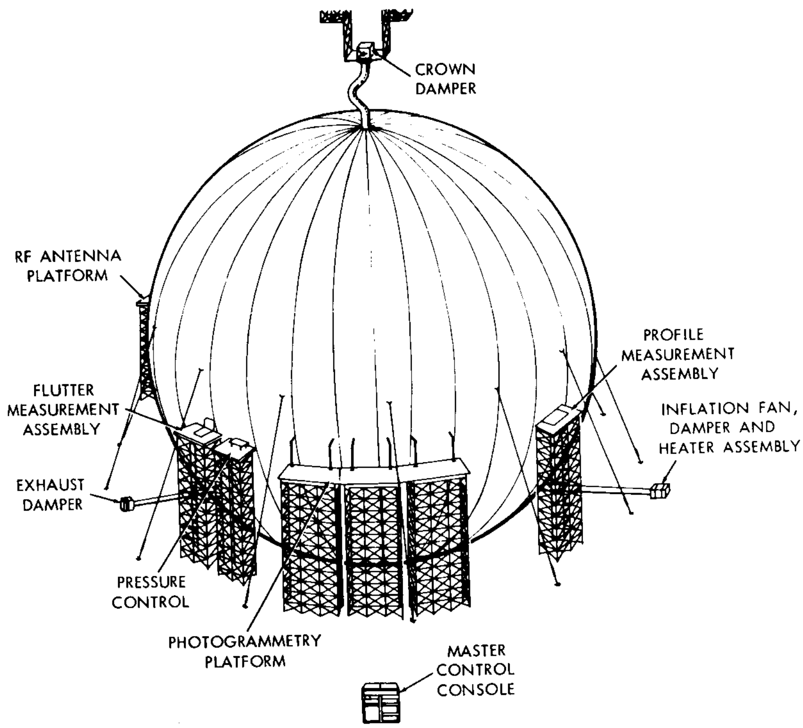


Figure 3. General Test Arrangement

A photogrammetric technique using stereo-photogrammetric cameras was selected for the primary method of examining the physical shape of the sphere. These cameras were mounted on a platform (see Figures 1, 2, 3) 57 feet high and oriented to obtain a stereo-photogrammetric model approximately 10 feet high by 17 feet long. The model was in a plane normal to the sphere surface 11 degrees below the equator.

The RF Measurements were made at L-band and C-band frequencies at each pressure level using equipment mounted on an elevated platform (Fig. 4). The receiving antennas were mounted on moving carts on the scaffolding 100 feet from the sphere surface. The transmitting antennas were fixed at both ends of the scaffold. The spheres were illuminated with vertical, horizontal, and cross polarization at a plane normal to the surface of the spheres and 10 degrees below the equator from a distance of 100 feet.

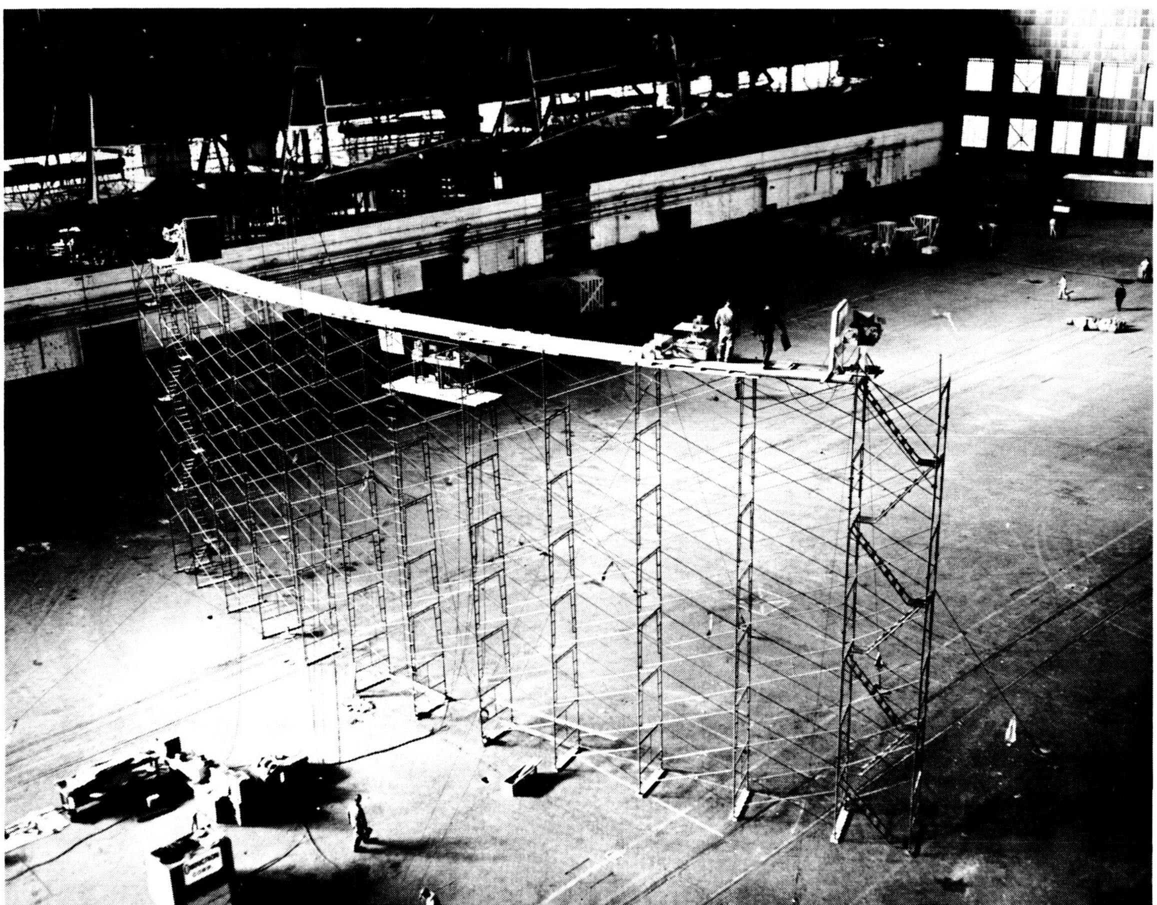


Figure 4. RF Equipment Arrangement

Gross translational and rotational motion of the spheres was determined using conventional surveyors transits. Skin flutter and ripple of the sphere skin was determined by proximity sensors also mounted on elevated platforms.

In order to determine the environmental condition associated with the sphere behavior, a small weather station was set up inside the hangar. This station was equipped to measure humidity, barometric changes, temperature gradients and changes, wind velocity and wind direction. The weather station was located at the master control station.

Test Procedure

The test spheres were prepared for inflation by extending them on a ground cloth inside the hangar. Helium was injected into the sphere for initial erection as shown in Figure 5. After the shpere had been partially erected by helium,

Figure 5. Initial Erection

warm air was added to fill out the sphere and to provide enough lift to raise it off the floor (Figures 6 and 7). Twelve tie down lines were adjusted to permit the sphere to "fly" about 6 to 8 feet above the floor level. The lenticular balloon was then inserted into the test sphere and inflated with enough helium to enable it to support the sphere in event of sudden loss of buoyancy.

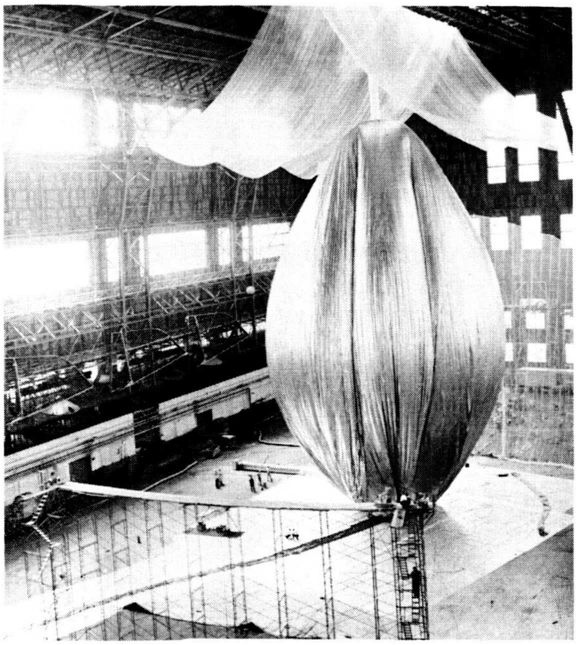


Figure 6. Inflation Continues

Figure 7. Inflation Nears Completion

The spheres were tested at nominal skin stress values which could be encountered in an orbital inflation with various inflating compounds. The skin stress values were controlled on the basis of differential pressures. The following table indicates the stress levels and corresponding differential pressures at which the RF backscattering and structural tests were to have been performed.

Nominal Skin Stress (psi)	Differential Pressure (inch water)
400	0.010
700	0.018
1500	0.038
2800	0.070
4800	0.120
7400	0.185
9400	0.235

Between each stress level the pressure was relaxed to 0.01 inches of water (400 psi) at which time the tests were again performed to determine the point at which the sphere had achieved its "memory" state, simulating rigidization in orbit. Following this sequence of pressures the spheres were to have been subjected to increased pressures until rupture occurred.

As the test proceeded, data was carefully collected on sphere motion, skin flutter and ripple, skin texture, and sphere temperature and pressure.

RF Backscatter Measurements

The test plan for determination of the RF backscatter characteristics consisted of two parts: (1) RF survey of the hangar without a sphere in position, and (2) measurements of the sphere. The RF survey of the hangar was used to determine the location for the RF equipment and the residual background levels.

For testing of the spheres, the receiving antennas were mounted on moving carts on a scaffolding as shown in Figure 4, 100 feet from the sphere surface. The transmitting antennas were fixed at both ends of the scaffold. The antennas were directed toward the sphere center, or 10 degrees below the equator at the surface. The transmitter, receivers, and recording equipment were located below the antennas. This arrangement permitted determination of the backscatter characteristics of a 30 degree sector of the sphere.

The frequencies used for the tests were L-band (1.71 Gc) and C-band (5.65 Gc and 5.85 Gc). Typical backscatter patterns from the sphere are shown in Figure 8. The top curve shows the return signal recorded at the initial sphere skin stress of 400 psi. The lower curve indicates the return signal also at 400 psi but after the sphere had been stressed to 7400 psi. The return obtained after stressing is much smoother than that of the unstressed condition.

The RF measurements indicated that the backscatter characteristics improved as the internal pressure was increased (and then relaxed) and approached the design levels in the frequency bands tested.

The RF data also indicated that no apparent improvement in the backscatter characteristics was realized upon increasing the stress above the 7400 psi level.

Structural Evaluation

Photogrammetry — A photogrammetric technique was employed for examining the physical shape of the sphere (Goddard was assisted by the Army Map Service in conducting these tests). This method of stereo mapping irregular

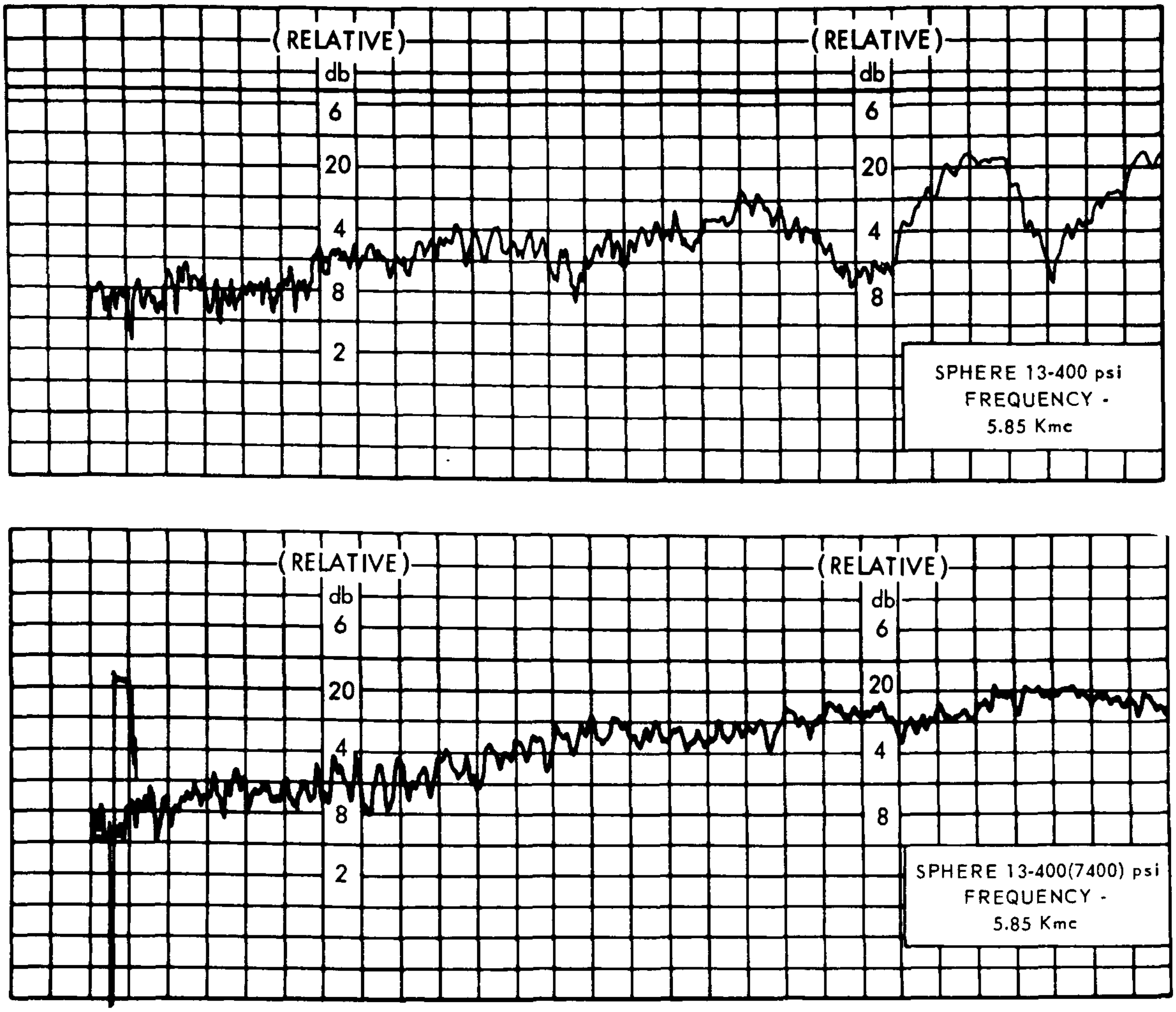
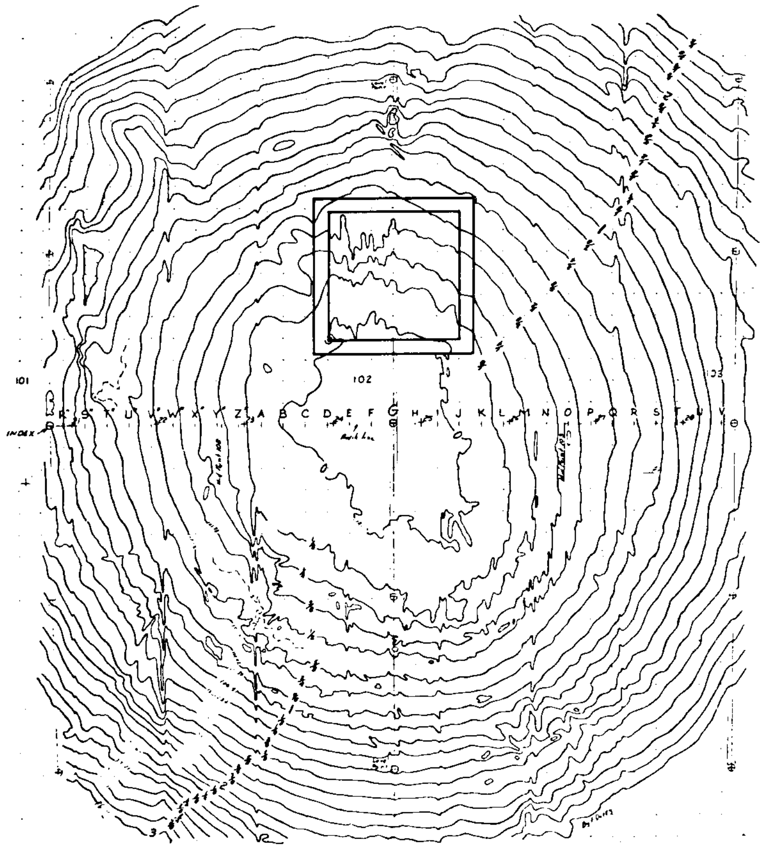
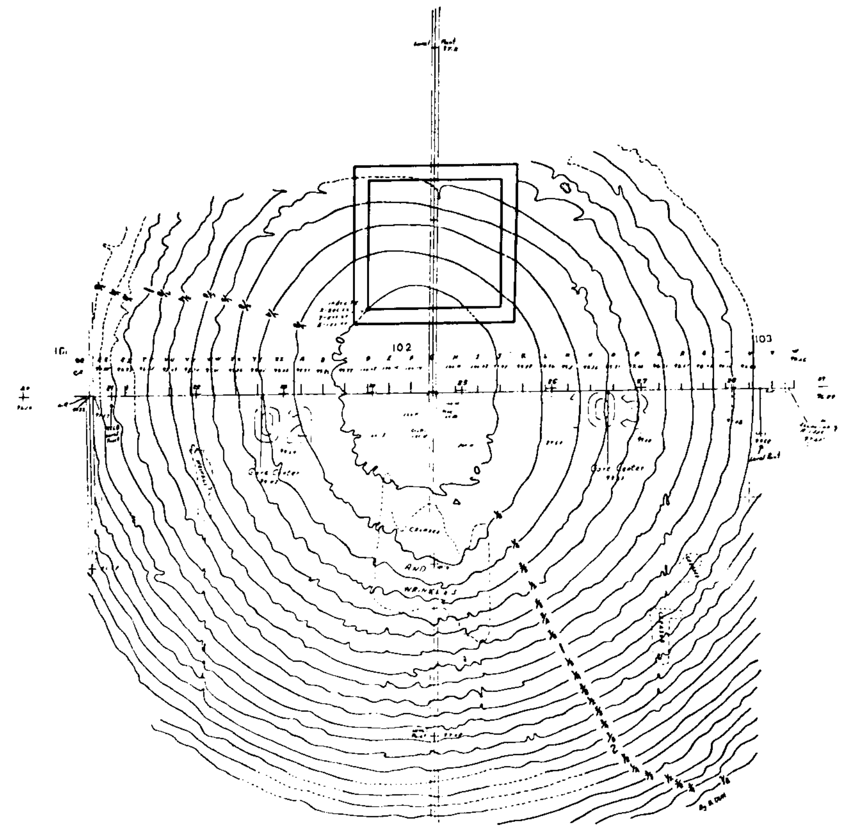


Figure 8. Typical RF Test Patterns

surface areas is a proven technique. Stereo photographs were taken at each of three positions about the sphere. Each position comprised an area about 10 feet square and spanned 2-1/2 gores. The contour plots consisted of a series of contour lines drawn for every 1/8 inch drop in elevation from the high point. Two Wild RC-8 precision aerial cameras, modified to a finite focal distance of 12.9 feet, were used. The film used was aerographic, stable base, high contrast, Dupont type 140 Cronar film. The cameras were mounted on a dolly positioned to obtain a stereo-photogrammetric model about 10' wide and 17' long. The model was in a plane normal to the sphere surface at 11 degrees below the equator. Typical contour plots made from the photogrammetric data are shown in Figure 9. The top plot shows a very rough sphere surface at the 400 psi stress



SPHERE 13 400psi



SPHERE 13 400psi (7400psi)

Figure 9. Typical Contour Plots

level. The bottom plot shows definite improvement in the contours at the 400 psi level after stressing to 7400 psi.

In addition to the contour plots, profile plots were also obtained from the photogrammetric data. Typical profile plots are shown in Figure 10. It is readily apparent that considerable improvement was obtained after the 7400 psi stress level was reached and then relaxed to 400 psi.

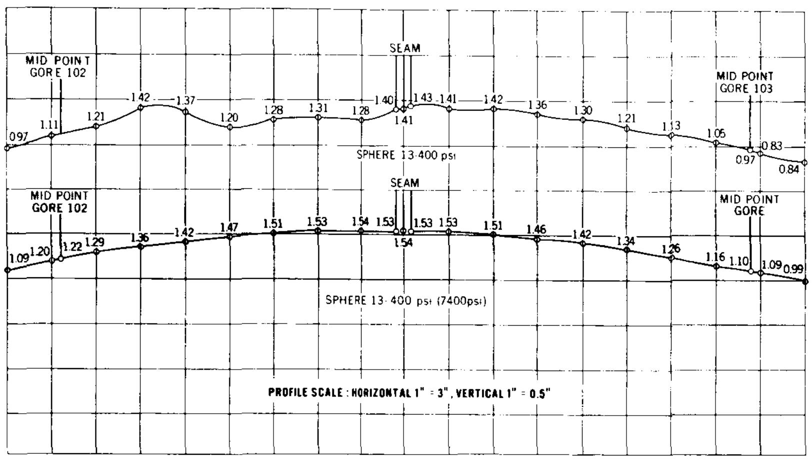


Figure 10. Typical Profile Plots

The photogrammetric contour and profile measurement data did not provide adequate information for absolute determination of the sphere shape as a function of internal pressure. However, a qualitative evaluation indicated an improvement in the overall shape and surface characteristics of the sphere.

Skin Texture

Photographs were taken of the sphere surface to determine skin texture as a function of pressure. Twelve areas were selected on each sphere for photographic examination. Typical photographs are presented in Figures 11 and 12 at 400 psi before and after stressing to 7400 psi. It can be seen that there was a definite improvement in the skin texture as the skin stress was increased and then relaxed. The improvement was most pronounced after achieving the 7400 psi stress level. This is in agreement with and supports the results of the RF and photogrammetric contour and profile data.

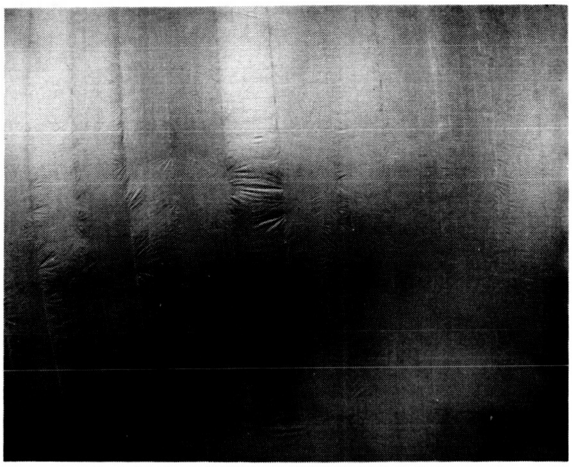


Figure 11. Skin Texture - 400 psi

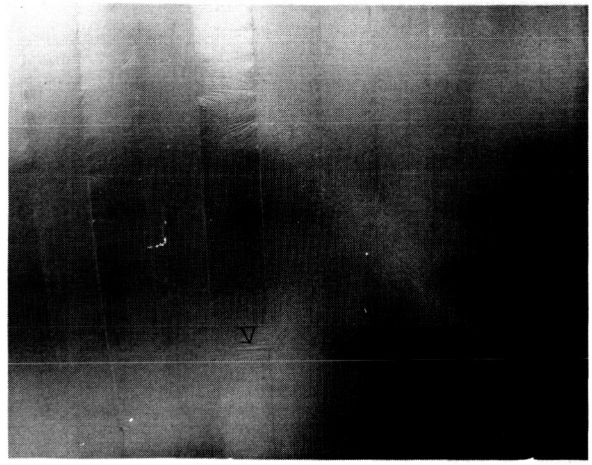


Figure 12. Skin Texture - 400 psi (7400 psi)

Ultimate Strength

Four spheres were tested at Lakehurst. The rupture pressures for the spheres are presented in the following table.

Sphere	Test Date	Ambient Temperature (°F)	Rupture Stress (psi)	Cause
9	6/63	70-80	4,200	Appendage Stress Area
11	6/63	70-80	6,200	Material Defect
13	7/63	70-80	11,200	Appendage Stress Area
16	12/63	30-34	23,000*	

*17,000 psi when corrected for temperature.

The burst stress in the 70-80 degree F range was estimated to be between 12,000 and 18,000 psi. The premature rupture of spheres 9 (4200 psi) and 13 (11,200 psi) (Figures 13 and 14) were attributed to the high stress areas associated with the inflation appendages. The rupture of sphere 11 (Figure 15) at 6200 psi was caused by a material defect.

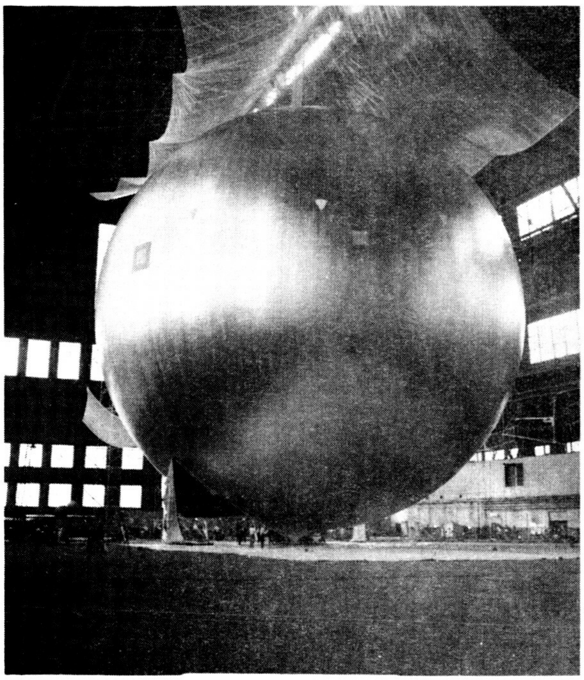


Figure 13. Sphere 9 Rupture

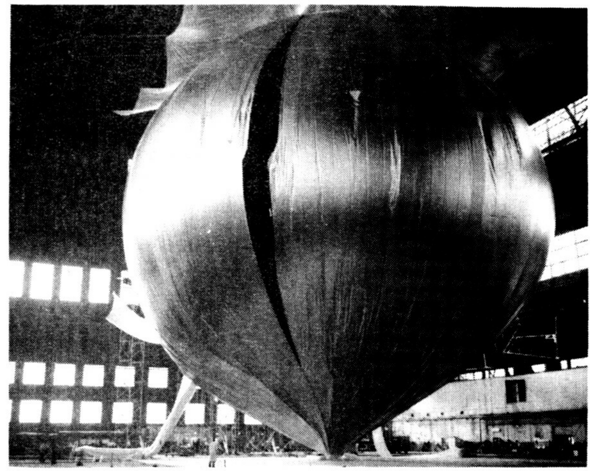


Figure 15. Sphere 11 Rupture

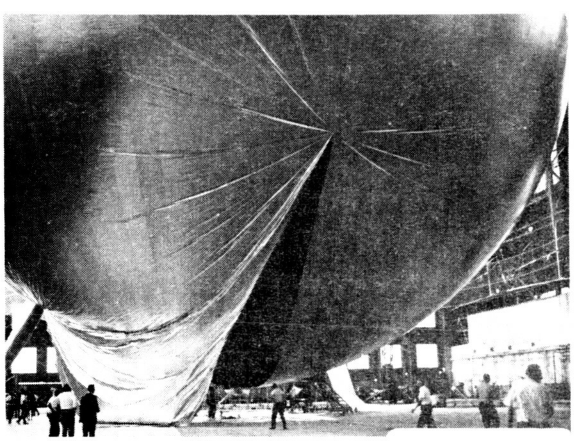


Figure 14. Sphere 13 Rupture

Gore material in the immediate area of the ruptures of all test spheres was removed (Figure 16) and examined for cause of failure. For sphere 11, visual inspection, later confirmed by photomicrographs (Figure 17), resulted in the conclusion that faults existed in the material. The inner Mylar layer of the three-ply laminate contained numerous folds which were hidden by the outer layers of aluminum. As the material was stressed during inflation, the aluminum yielded first, causing the Mylar to unfold suddenly and rupture. Sphere 16 was fabricated under improved lamination and fabrication processes. The material which went into this sphere was typical of the final orbital flight sphere 18 and

Figure 16. Removal of Sample Material

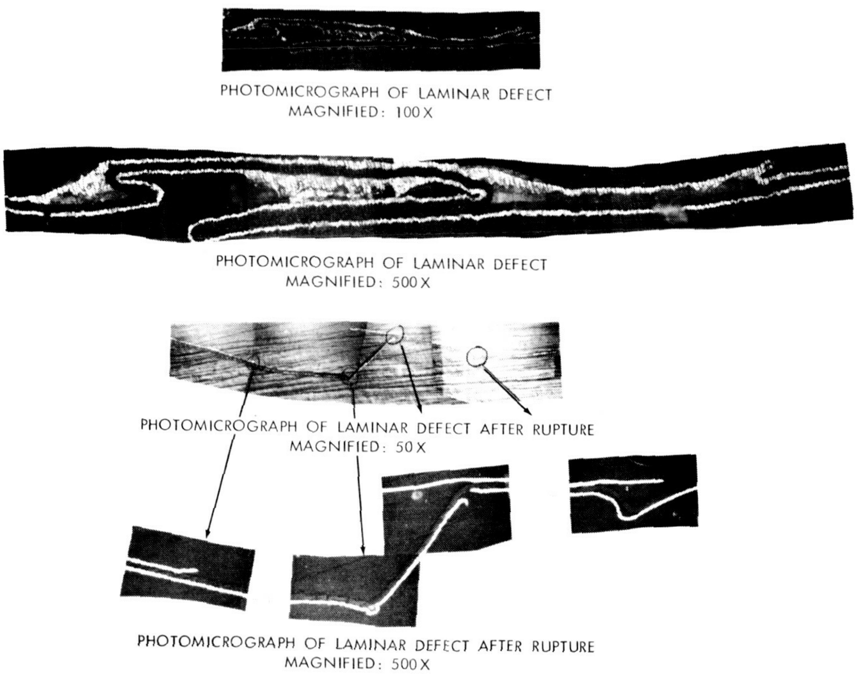


Figure 17. Echo II Material Defect

the backup sphere 17. The apparent high rupture point of 23,000 psi is attributed to the low temperature characteristics of the laminate. Laboratory tests indicated that stiffness increased about 34% from room temperature to freezing temperatures. The summer tests were conducted at 70-80 degrees F while the December test was conducted at about 30-34 degrees F. Correcting the low temperature stress of 23,000 psi to the 70-80 degree F temperature range yields a stress value of about 17,000 psi.

Despite the premature failure in three of the four test spheres, the ultimate strength of the flight quality sphere was demonstrated to be excellent.

Environmental Conditions

During testing for the structural and RF backscatter characteristics of the test spheres, the effects of a number of prevailing environmental conditions had to be determined and/or corrected. These included ambient temperature and pressure, air currents, and the effects of these parameters on sphere motion and skin flutter.

Extreme temperature variations could affect the lift or buoyancy control of the sphere. During the summer tests the mean temperature range was 60 degrees F low to 80 degrees F high and the time lag of hangar temperatures relative to the outside was about 2 hours. The maximum temperature gradient within the hangar was about 15 degrees F over a height of 150 feet and was observed during the hottest part of the day. It was also noticed that the coldest temperature occurred at about a height of 10 feet above the floor. The prevailing temperature environment was much better than had been anticipated and had little effect on the test.

The December test was affected considerably by the cold weather and sudden temperature changes. The maximum temperature in the hangar on the test day was 35 degrees F. During the test period, a cold front accompanied by strong winds and snow, caused the temperature to drop sharply. Considerable difficulty was inflicted on the sphere pressure and buoyancy control and forced an accelerated test schedule.

Air currents within the hangar were determined to be small. However, gusts recorded for short periods (less than 1 second duration) varied from 50 to 75 feet per second, with the mean current being less than 5 feet per second. Air flow appeared to be a circulating current in the direction of the hangar length. Minimum air current was registered at about the 75 foot level, which coincided with the center of the sphere.

The gross movement of the sphere in translation and rotation was of interest due to its possible affect on the RF backscatter measurements. Such motion has the effect of moving the sphere out of symmetry with the axis of RF energy propagation which could affect the backscatter behavior. Conventional surveyor's transits were positioned about 120 feet from the sphere on the catwalks at the 71' level. Vertical and horizontal motion was measured by viewing graduated tapes attached to the sphere surface. Two 16 mm movie cameras with automatic control were located adjacent to two transit positions, and focused on the graduated tapes at the sphere equator. The cameras took time lapse photographs every two seconds of the sphere motion.

It was determined that sphere stability was poor at the start of each pressurization cycle but improved as the pressure increased. Inspection of the films indicated that the sphere was in continuous random motion with maximum displacement between frames of about 24 inches. It was determined early in the test that this random motion had a negligible effect upon the RF measurements.

The presence of flutter or standing waves on the sphere surface and ripples or travelling waves over the surface was also considered to have possible detrimental effects on the RF test behavior of the spheres. A flutter and ripple measurement device was developed which consisted of three proximity sensor units. These units carried four static sensors within 0.02" of the sphere surface. The static sensors picked up skin surface variations over a 2-1/2 square foot area when held parallel with the plane of that surface. The sensors produced traces on an oscillograph recording. Upon examination of these tapes actual fluttering motion of the skin surface was difficult to detect. The amplitude of the local pertubations was so small it was masked by the gross motion of the sphere. The RF data indicated that the fluttering motion of the sphere surface produced no appreciable effect on the signal return.

It can be concluded that skin flutter levels were minimal and could not be detected by the flutter sensors. Introduction of a deliberate flutter of measurable magnitude had no appreciable effect on the RF backscatter measurements.

SUMMARY AND CONCLUSIONS

The successful conduct of the Echo II test spheres shows that meaningful static tests of inflatable structures of this type can be conducted over a long period of time, when adequate controls and safeguards are provided. Such tests can provide a method for evaluating the structural integrity of the spheres by revealing defects in the basic material and its method of fabrication.

More specifically, the RF backscatter measurements on the Echo II test spheres indicated that the radar cross-section and scintillation levels improved as the internal pressure was increased (and then relaxed) approaching the design levels in the frequency bands tested. Although the photogrammetric contour measurement, profile measurement, and skin texture data did not yield adequate information for absolute determination of the sphere shape as a function of pressure, it did provide a qualitative evaluation indicating a general improvement in the overall shape and skin texture. This was in very close agreement with, and verified the results of the RF tests.

Despite premature failure in three of the four test spheres, in one case due to material defects and in two cases due to test appendage stress areas, the ultimate strength was demonstrated to be excellent in the flight quality sphere.

Evaluation of the test results indicated that in order to attain optimum backscatter characteristics, it would be necessary to pressurize the orbital Echo II sphere to the equivalent of 7400 psi at about 75 degrees F. Since the properties of the Echo II material are a function of the ambient temperature, and since the expected temperature of the orbital sphere was about 195 degrees F, it was determined that pressurization to about 4700 psi skin stress at 195 degrees F would provide the necessary surface characteristics for optimum reflection of RF energy. Collection of the backscatter data over a wide range of sphere conditions has provided a basis for better evaluating the structural surface of the orbiting satellite.

The overall conclusion can then be reached that the test was a success with all the planned test objectives being satisfactorily achieved.

ECHO II TELEVISION SYSTEM

by J. Yagelowich, Goddard Space Flight Center

SUMMARY

Environmental testing of the huge 135' diameter Echo II satellite sphere was conducted by launching a test sphere into a ballistic type trajectory in order that an evaluation of spacecraft operation could be made in a space environment. The test was complicated by the fact that spacecraft operation took place at an altitude such that proper visual observation of its performance was impossible with existing ground facilities. This problem was solved by instrumenting the launch vehicle with a television viewing system for close range observation of the spacecraft operation. A very careful study of the project requirements versus equipment and facilities was made prior to establishing the final system configuration. The system worked as planned during two vertical tests at Cape Kennedy, Florida and during the orbital launch from the Western Test Range. Excellent pictures were obtained of the Echo II spacecraft operation including deployment, inflation and injection into orbit. Additional uses of this type of real time TV system is being considered by NASA for future satellite projects.

INTRODUCTION

Prior to the orbital launch of the Echo II satellite, it was desirable to test spacecraft operation in a space environment. Because of the large area required to conduct such tests, it was necessary to launch the sphere in a ballistic trajectory so that spacecraft operation would take place in a space environment. However, spacecraft operation occured at an altitude such that adequate visual observation of its performance was not possible with existing ground equipment. It was therefore decided to instrument the launch vehicle with a movie camera and a television system to provide a means of visually observing spacecraft operation at a much closer range.

The operational sequence of the Echo II spacecraft is illustrated in Figure 1. The project plan for environmental tests of the spacecraft operation required that these various operational sequences be closely observed during the vertical tests which were to be conducted at Cape Kennedy, Fla.

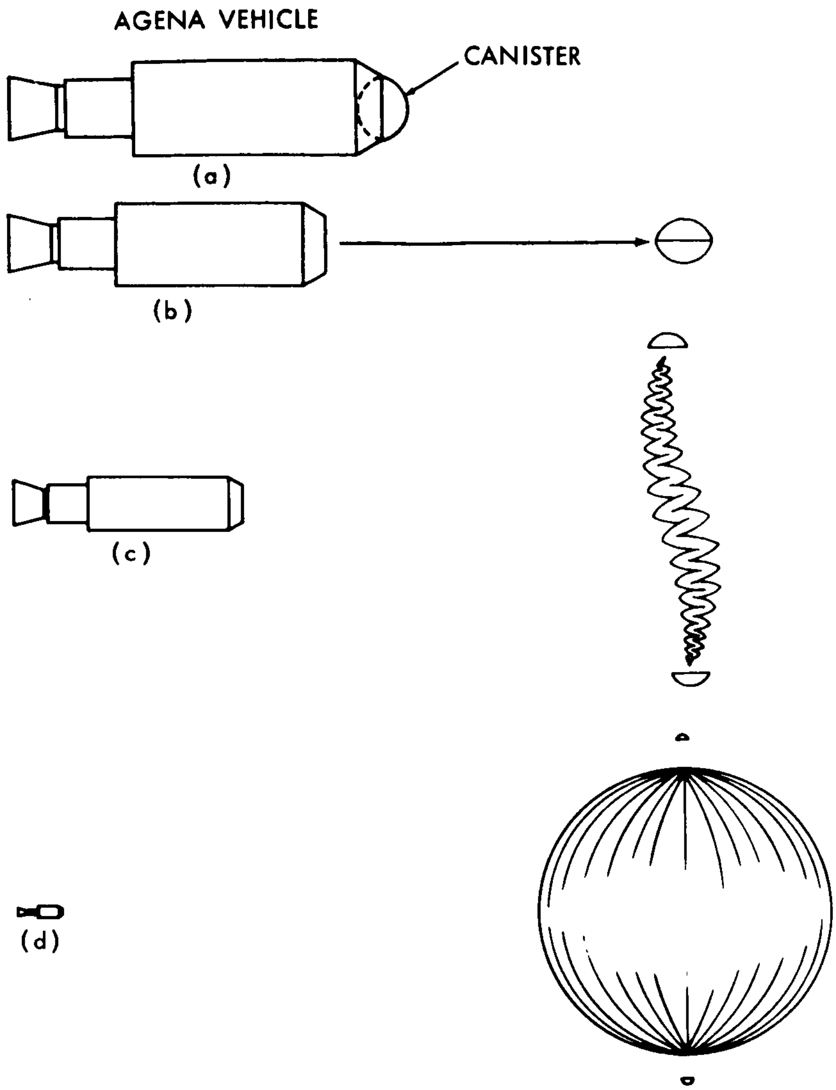


Figure 1. Operational Sequence of Echo II Spacecraft

The viewing system was required to provide confirmation of the following events, with a high degree of resolution:

- Canister ejection from the launch vehicle
- Canister opening and test sphere deployment
- Initial inflation of test sphere

Figure 2 is a sketch illustrating the major operational sequences involved in the tests.

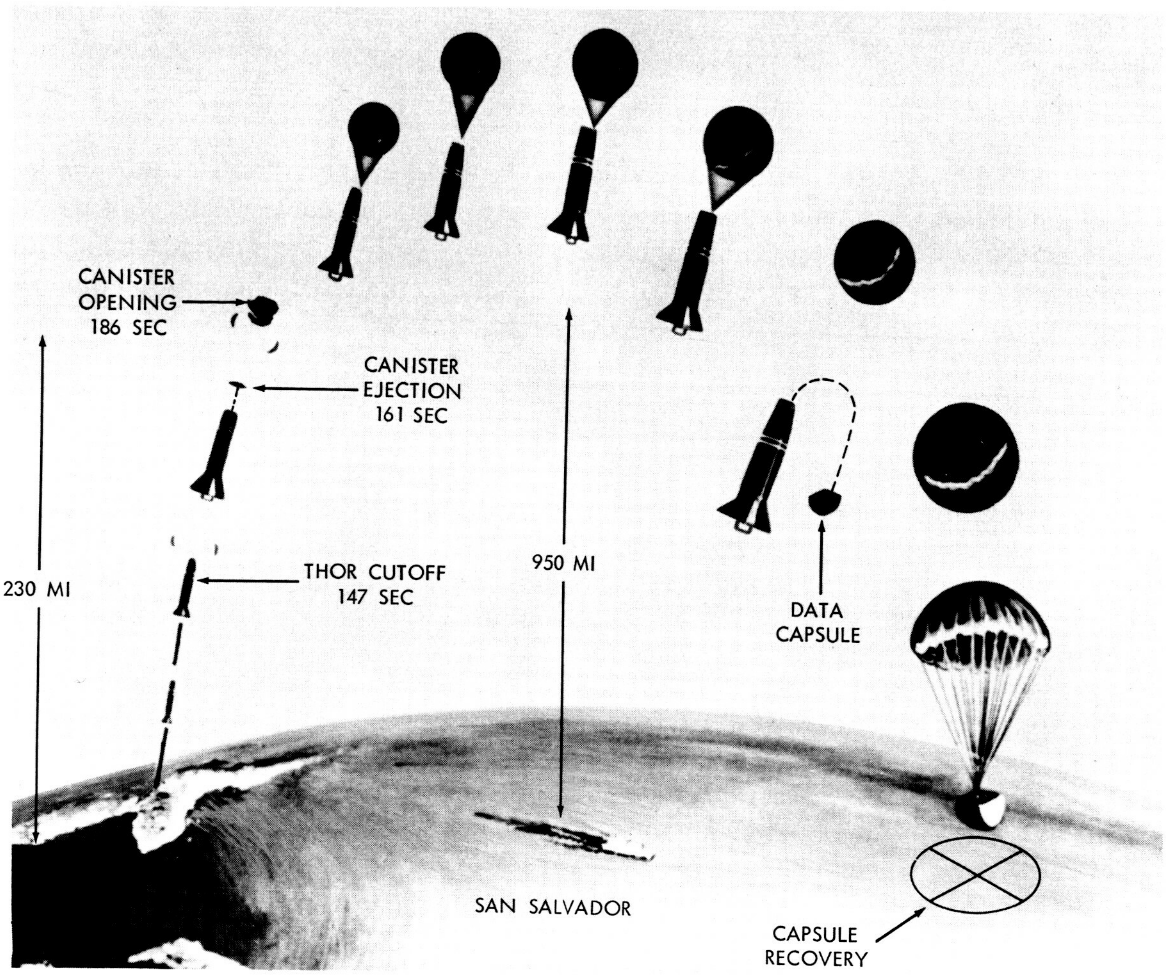


Figure 2. Vertical Test Launch Trajectory

The most critical portion of the test occurs within the first minute after opening of the canister halves is initiated. During this time the deployment of the sphere takes place. As the sphere is released from its container, residual air within the folds expands and initiates sphere inflation. Continued inflation and full pressurization is accomplished by means of an inflatant compound contained within the sphere. Seeing the detail of this portion of the flight was the major objective of the viewing system.

The following describes some of the problems involved with the design and application of the television system and the results obtained.

SYSTEM DESIGN

General

Prior to defining the television system to be used in these tests it was necessary to conduct a very thorough study of the performance requirements for the system as a result of the system requirements. Early in the review for schedule reasons the decision was made to utilize existing equipment in the major components of the system.

MODEL STUDIES

Subjective features in evaluating TV picture quality such as contrast, brightness, object form, object illumination and object motion were considered. Since these are interrelated in a complex manner, definitive settings and numbers for general situations are hard to define. In some cases, only an actual simulation will suffice. Therefore, in order to become more fully acquainted with the viewing problems model studies were performed.

In the model study, as well as on the test flight, no modifications to the satellite were to be made to satisfy the TV requirement. However, changes could be made to the canister (the container into which the satellite was folded and housed for launch) in the form of type of paint, and painted patterns.

The model study objectives were conducted to:

- Determine the optimum viewing illumination angle (i.e., sunlight to satellite to camera angle)
- Compare diffuse and specular reflectors
- Determine lens exposure setting
- Determine effects of light filtering, image retention, and object motion on the TV picture

The test setup was scaled to simulate flight conditions as indicated in Figure 3. Models were made of the satellite canister, folded satellite, and inflated satellite using actual materials, paints, etc. Lighting conditions were simulated by using a carbon-arc searchlight as a sun. Walls, floors, strings or other supporting devices reflect enough light to become bothersome and to give misleading results. Therefore, strict control of lighting was exercised. A closed circuit

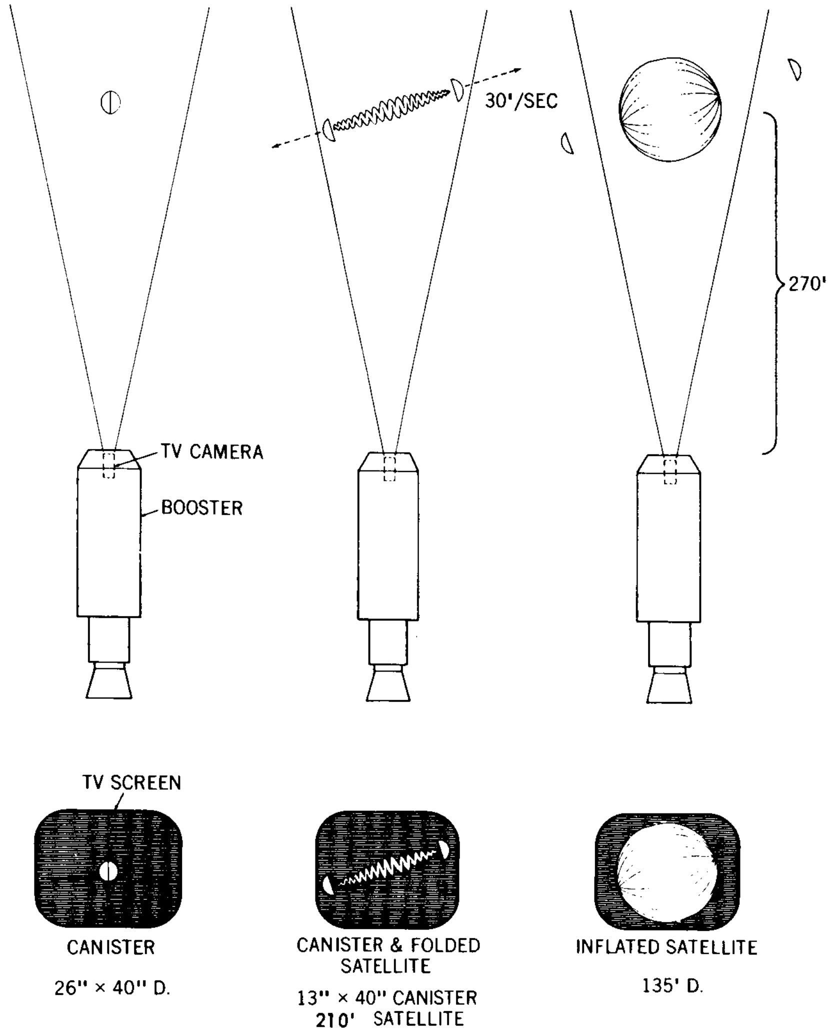


Figure 3. Inflation Sequence of Satellite

TV system, having nearly the same characteristics as a flight camera, viewed the simulations while lens settings, model distance, illumination angle, etc., were changed.

Figure 4 shows the TV image of a partially inflated model of the Echo II satellite, while illuminated by the searchlight. The TV image tends to have highlights—areas of saturated white or black with little light values in between. Also, the blooming effect of the saturated white areas is apparent with loss of detail in adjacent areas. The Echo II fabric is a 71% efficient reflector of light. This efficiency, combined with the high intensity of sunlight, means a surplus of

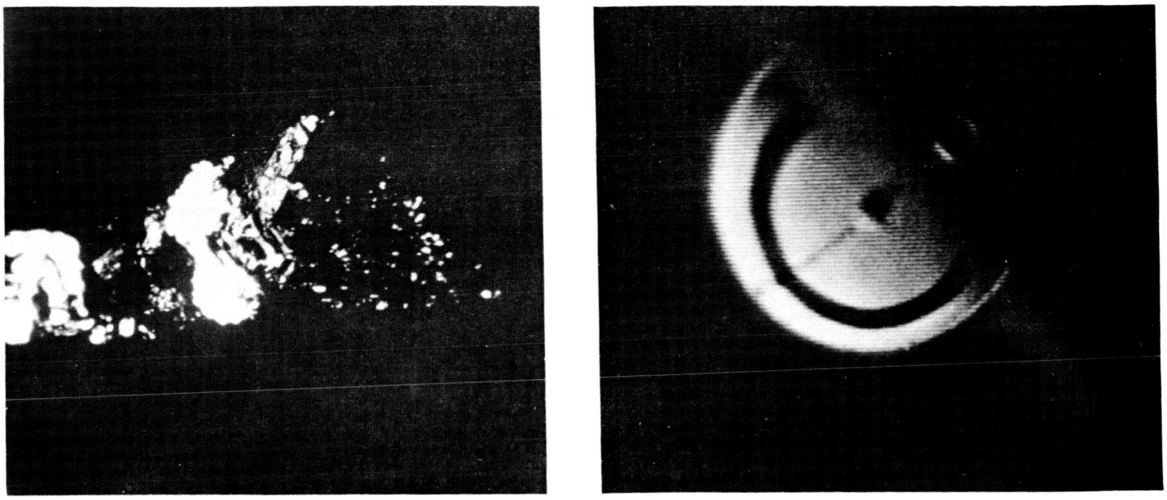


Figure 4. Specular Versus Diffuse Reflector

light from the highlight areas, and Figure 4 indicates there is a problem of contrast ratios.

At first, it was thought the canister should also be a specular reflector to match the satellite but the model study showed only a pin point of light was then visible, such as one of the smaller dots of light in Figure 4. By coating the canister with flat white paint, to make it a diffuse reflector, considerable improvement in viewing capability was obtained, as the right half of Figure 4 shows.

Each of the flight cameras had to be calibrated using models and carbon arc lamp to compensate for inherent differences in camera sensitivity. A correction to exposure was needed since the searchlight's intensity is 6000 foot candles (F. C.) versus sunlight's 13,000 F. C. For the first test flight and the orbital launch a lens setting of f/22 was used, while for the second test flight the lens was set to f/16. A Wratten 47B filter (deep blue) was used to prevent thermal burning of the vidicon screen.

As a result of the model study, the following features were defined for the TV system design.

1. The canister opening speed plus the satellite unfolding rate required a high frame rate, such as 30 frames/sec.

2. The geometry of the objects being viewed (a 26" × 40" canister followed by a 135' diameter sphere at a distance of 270') established a requirement for a

system with at least 280 lines of resolution. This includes an allowance for the vehicle attitude control system.

Since the resolution of a TV system is a function of the number of scanning lines, and the allowable bandwidth, a 525 scanning line, 30 frame per second with a 4 megacycle video bandwidth system was found to be necessary to provide about 400 TV lines of resolution. With proper lens and viewing geometry selection, this system appeared to be suitable for Echo II. The wide bandwidth needed and the restricted transmitter power available required operation within range of a receiving station having an antenna of large gain so as to be able to achieve a suitable signal-to-noise ratio. Such a selection also permitted the use of standard components in ground recording and display equipment.

Various scan rates of available TV systems were also considered. The slow scan rates were rejected even though this technique has many advantages for space applications because of savings in power and bandwidth. However, the information rate obtainable was too low for Echo requirements. Also, the timing of exposure to occur just after canister opening was considered to be too unsure. This decision was justified when the satellite inflated so rapidly during the first launch that only a few frames of slow scan data would have been received and much of the inflation information would have been lost.

ADDITIONAL DESIGN CONSTRAINTS AND CONSIDERATIONS

In addition to the above, the following constraints were considered in the system design:

- As a result of a review of the literature on TV picture quality versus signal to noise ratio (SNR), in addition to tests conducted at GSFC, a SNR of at least 20 db was found to be required.

- The maximum slant range for the entire test flight was approximately 1000 miles.

- The availability of suitable receiving antennas at Cape Kennedy (60 foot parabolic reflector having 29 db gain) required the use of a 255 mc r. f. carrier.

- Due to the FM improvement factor, FM transmission was desirable in order to reduce transmitter power.

- The test schedule prevented development of optimized techniques.

These constraints led to a determination of the transmitter output power of approximately 50 watts.

SYSTEM DESCRIPTION

Figure 5 shows the flight components of the system as finally designed. The TV camera and transmitter (as well as the TV receiver and display) were supplied to GSFC by Lear Siegler, Inc. Total weight of the electronic components is 48 pounds, with 16-1/2 pounds devoted to batteries and 24-1/2 pounds to transmitter. The test program was liberal in the allotment of component size and weight, and the nature of the program was such that sophistication of design or manufacture was not required. For the orbital launch a decision was made to use the hardware flight proven in the vertical tests, thus precluding any redesign of components. However, significant improvements in system size and weight are possible. It is estimated that a total weight of 25 pounds for the flight package could be achieved with some redesign and repackaging, especially if the required r.f. transmission time were lowered from the 25 minutes obtained for Echo.

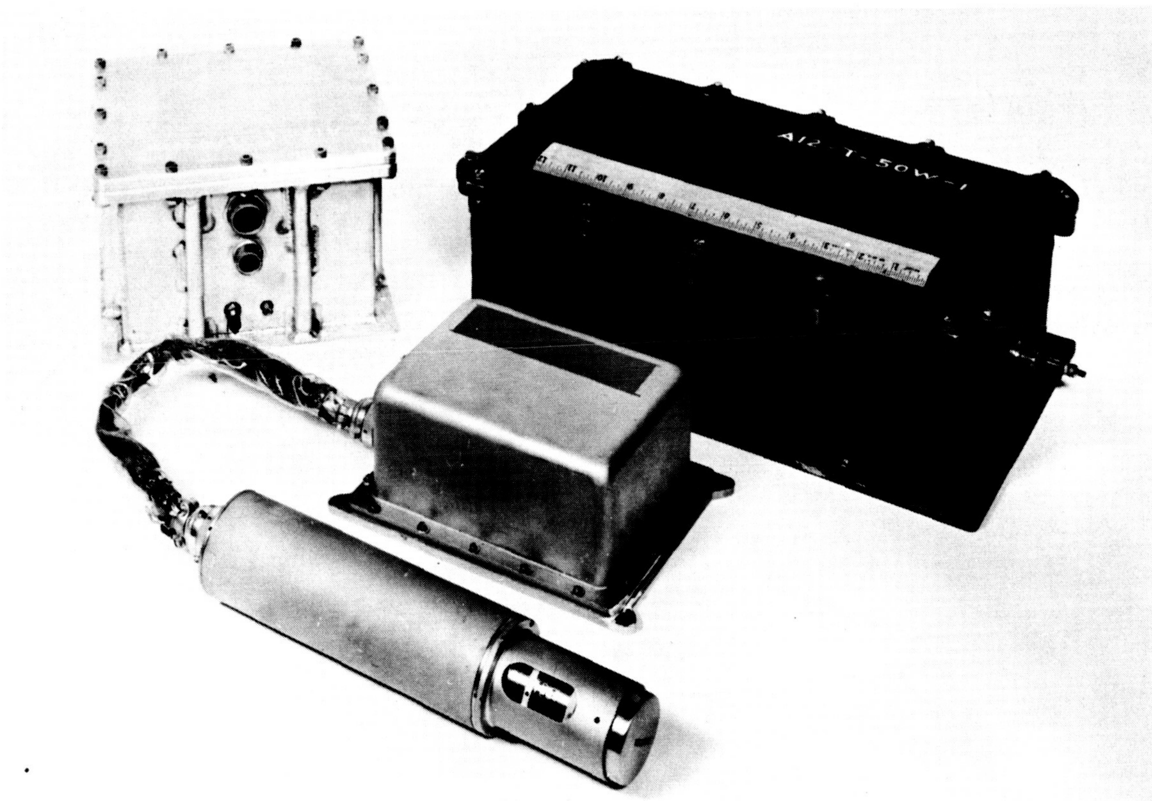


Figure 5. Vehicle TV System Components

The r.f. spectrum transmitted is shown in Figure 6. The video waveform is that of a test pattern. Modulation sense is upwards in frequency (i.e., saturation white is the highest frequency, and tip-of-sync is lowest). During the actual flight the spectrum was skewed to the high frequency side due to the video highlights.

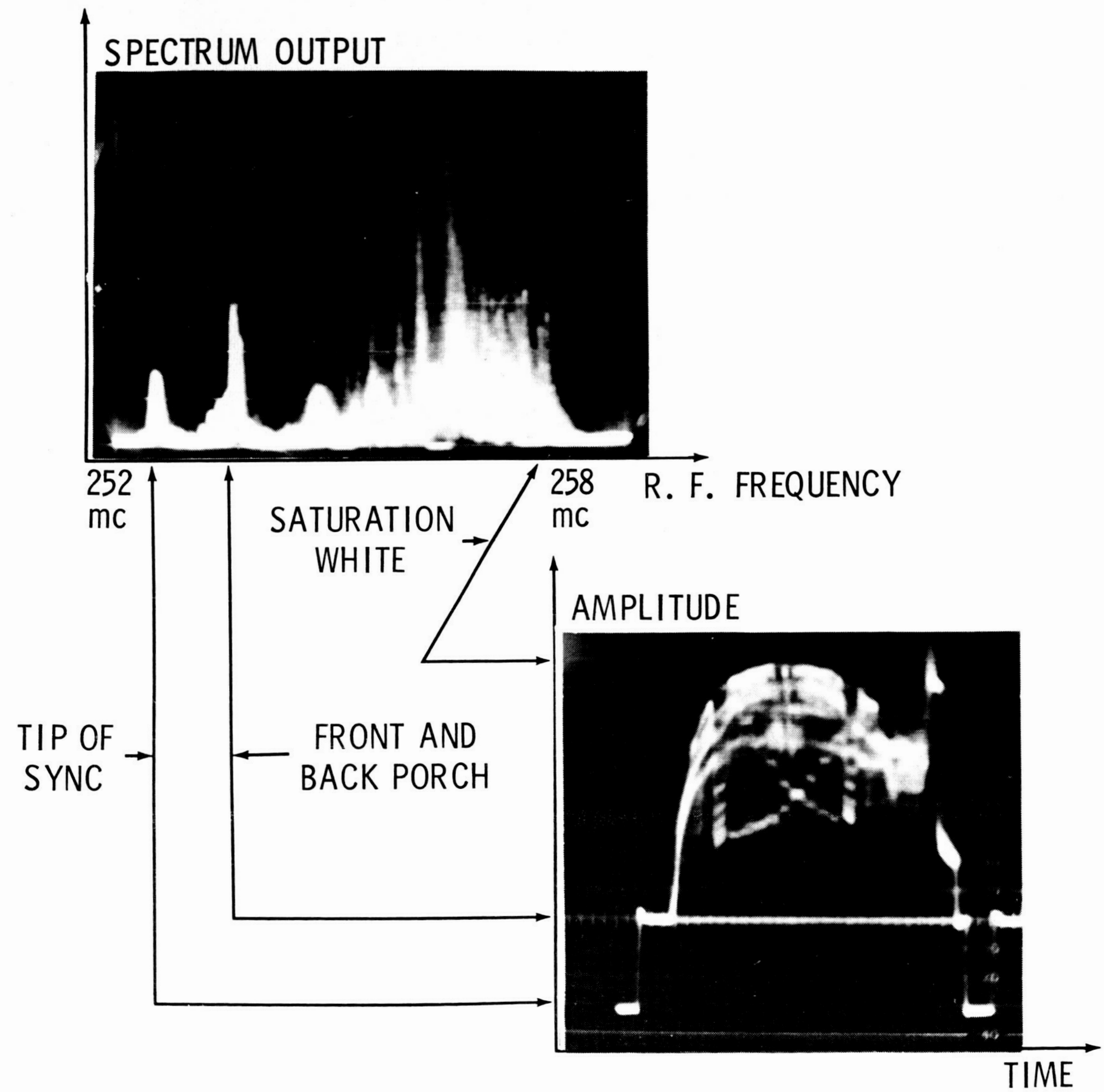


Figure 6. Relationship Between Composite Video and R.F. Spectrum

Two different transmitting antennas were used. For the test flights signal radiation back to Cape Kennedy was approximately along the aft axis of the Thor vehicle. In order to maximize received signal the transmitting antenna was designed to radiate maximum energy near the vehicle axis. Two monopole antennas, protruding from the side of the Thor, were used, spaced a quarter wavelength apart axially, and fed electrically 90° out of phase, which provided planar polarization.

The orbital Echo II launch required a different transmitting antenna design. In this case, the radiation needed to be approximately 90° from the vehicle longitudinal axis. This was accomplished by using a turnstile antenna mounted on the side of the Agena vehicle and facing the ground receiving station. Radiation is right circular polarization. The antenna was folded and covered during launch by the Thor-Agena adapter section. After separation of the two vehicles the antenna was erected prior to TV transmission. Figures 7 and 8 show the mounting configuration of the TV system in the Agena launch vehicle.

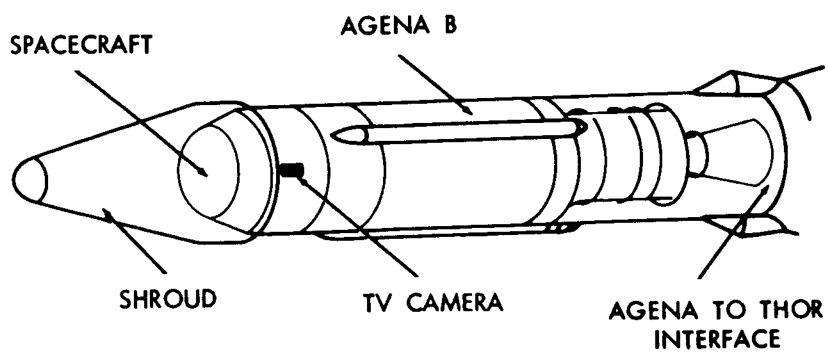


Figure 7. TV Camera Mounting in Agena

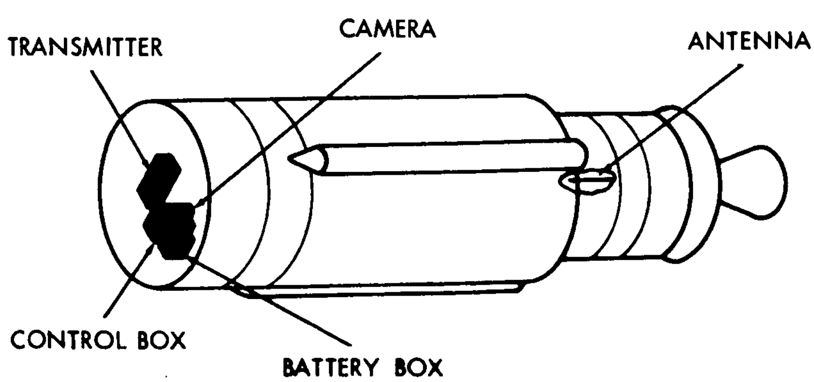


Figure 8. TV System Mounting in Agena

Considerable trouble with r.f. interference occurred with the ground receiver, which is conventional in design except for its wideband capability. The receiver achieved good amplitude and phase response by using very wide bandwidth stages throughout. It was susceptible to out-of-band signals because of its 3 db bandwidth of 13 mc. Many interference effects due to other transmissions were noticed at Cape Kennedy during the preparations for the vertical test flights. In order to prevent interference during the actual launch a clear channel from 240 mc to 270 mc was obtained as a precaution. In addition, a preamplifier, which had a bandwidth from 245 mc to 265 mc, was used ahead of the receiver to aid in reducing interference.

SYSTEM PERFORMANCE AND RESULTS

For the vertical test flights the TV system was turned on three minutes before lift-off. Transmission was received from this time through powered and coast flight for a total of 25 minutes. In the case of the orbital launch, a timer in the Agena vehicle turned on the TV system approximately 50 minutes after launch, just prior to spacecraft separation, and just south of the island of Madagascar. The TV system began transmission at a 1700 mile range, while near the horizon. Range closed to 1600 miles and then increased to approximately 2000 miles, before loss of usable signal took place. Total observation time was 14 minutes. In all cases, the receiving antenna automatically received the TV signal by tracking the launch vehicle telemetry signal.

During the orbital Echo II launch, and during the two vertical ballistic launches, the TV system clearly showed canister ejection, canister opening, and subsequent satellite deployment and inflation.

At the Pretoria receiving station, a signal level of -78 dbm was received at TV turn-on. This compares favorably with a calculated value of -76 dbm. A TV picture was received for about 14 minutes at which time radio horizon was reached and the TV signal was lost. At this time, the slant range was beyond 2000 miles, and the picture was still usable although quite noisy.

The inflation sequence of the Echo II satellite as transmitted by the TV system is seen in Figure 9. Some loss in resolution is incurred in photographing a TV monitor. Fuller appreciation of TV results can be gained by viewing a playback of the video tape recording rather than by examining photographs. In Figure 9 earth reflected light aids in the illumination of one side of the satellite and consequently enables more detail to be seen.

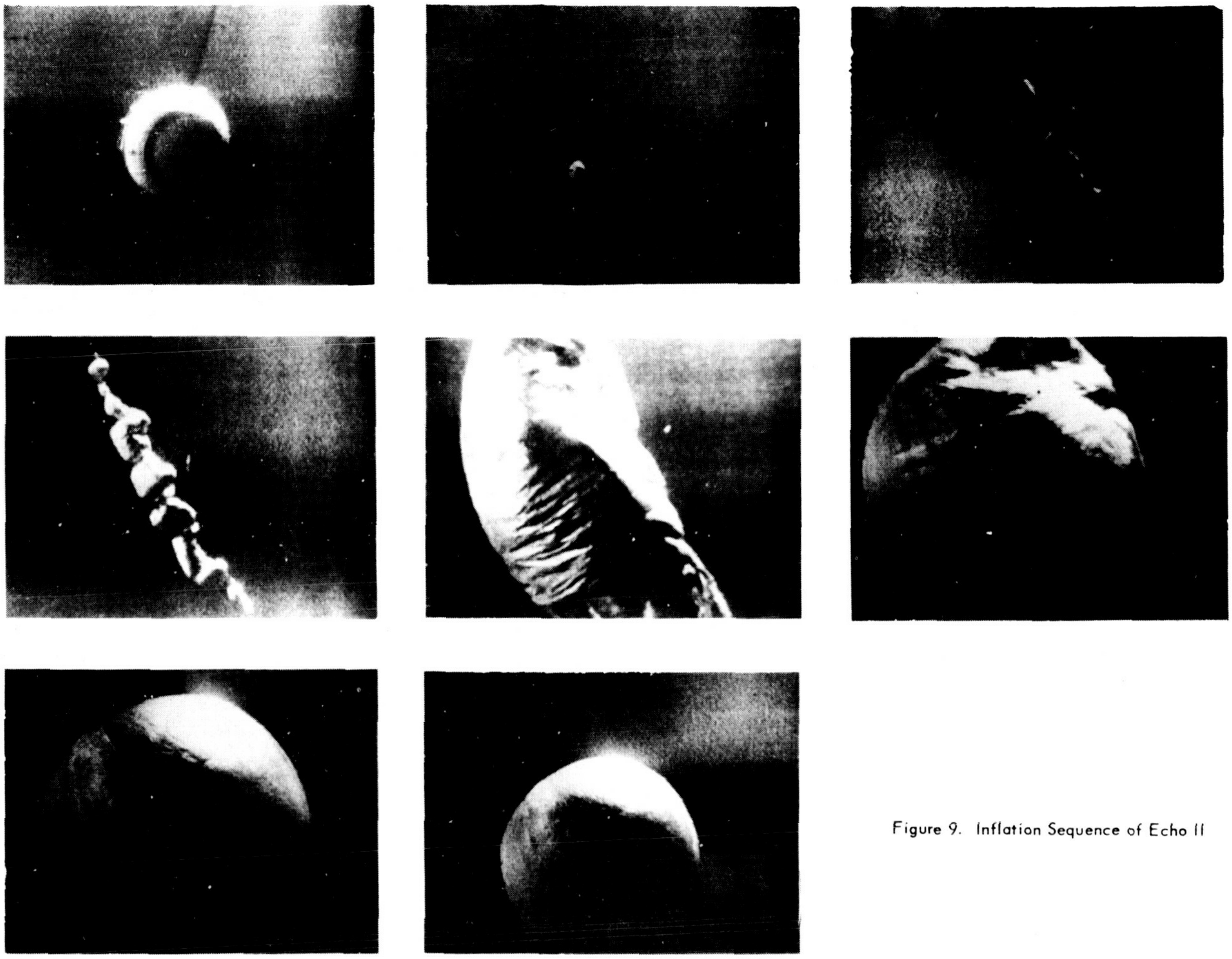


Figure 9. Inflation Sequence of Echo II

SOME FUTURE APPLICATIONS FOR REAL TIME TV

NASA is considering the future uses of real time TV in two applications. The first is with a geodetic satellite of the Echo type. The TV system will provide observation of the same type of spacecraft operation as that of Echo II.

The second TV usage in the planning stages is with Goddard's Applications Technological Satellite (ATS). A pictorial representation of the satellite is shown in Figure 10. The purpose of TV is to provide information on the operation of gravity orienting booms employed with the satellite's gravity gradient system. In the lower portion of Figure 10 is depicted what the TV image may be like. Since the satellite has wide bandwidth TV capability for its role as a communications repeater satellite, it is only necessary to add TV cameras, video

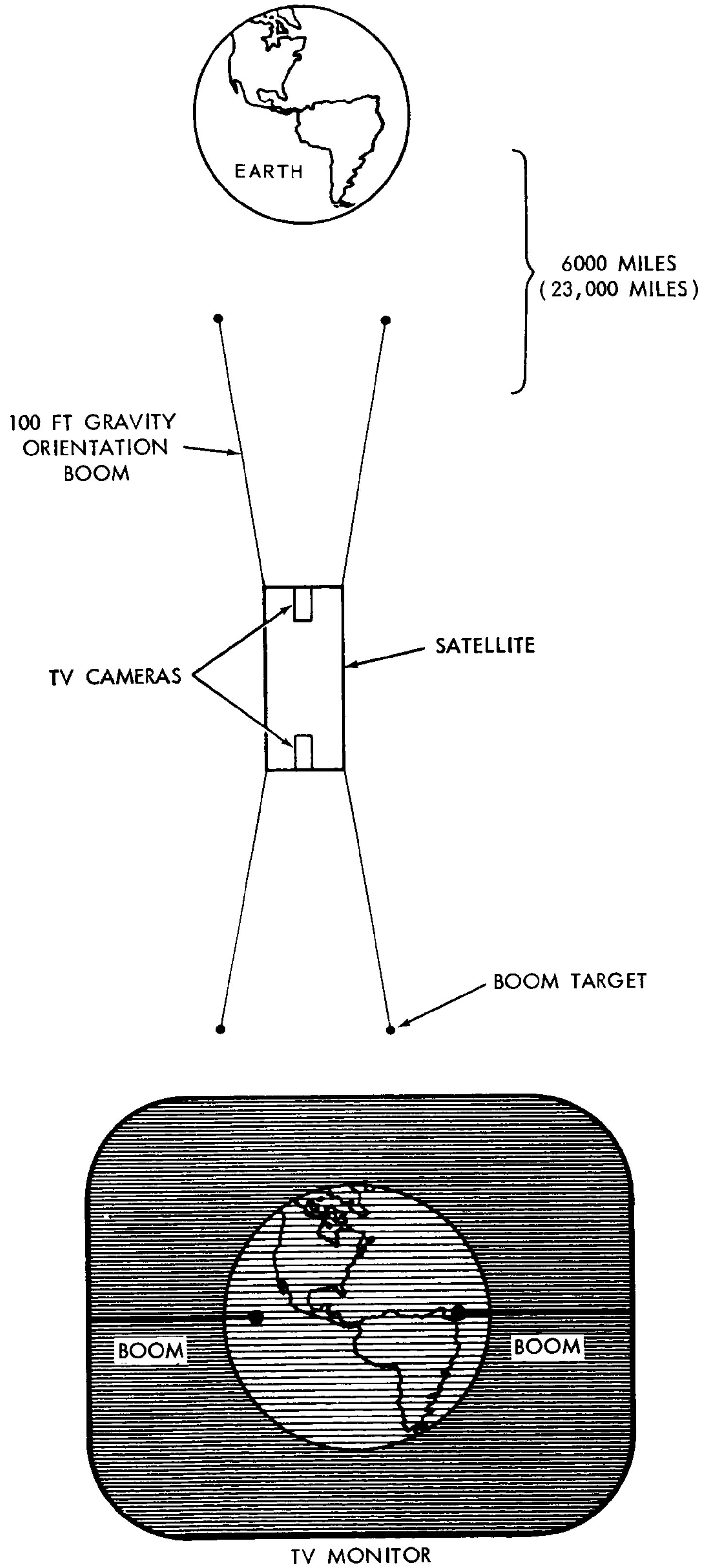


Figure 10. Pictorial Representation of Applications Technological Satellite

switching, and also to add at the end of each boom viewing targets for TV so that the end of the boom can be more easily seen. One of the TV pictures of a model study done for this program is shown in Figure 11. A cloudless portion of the earth is shown. The two bright spots near the edge of the earth are the two boom targets. The simulated left-hand boom has pronounced bending. Around the edges of the TV raster is a simulated grid (which would be etched into the vidicon screen) which is for scaling purposes.

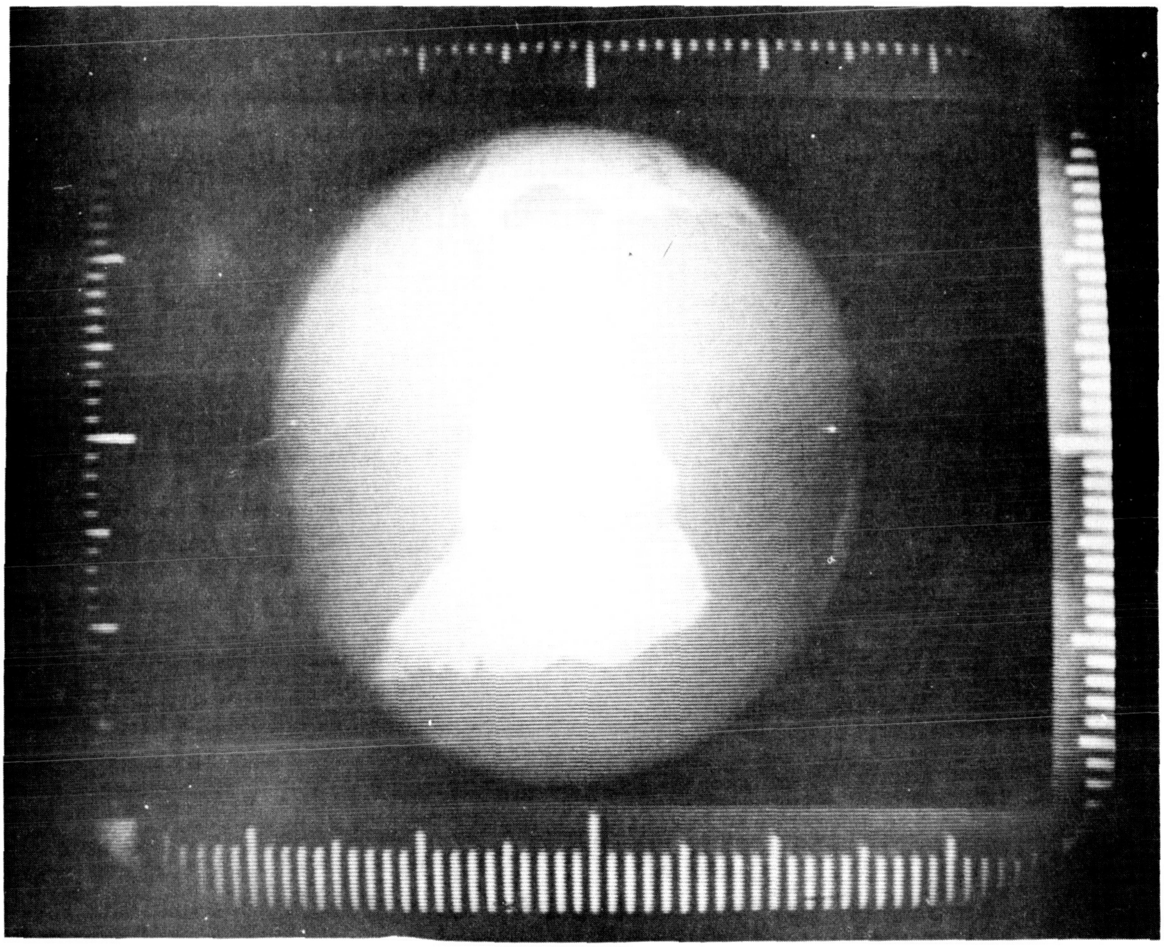


Figure 11. TV Picture from ATS Model Study

CONCLUSIONS

The Echo II TV system provided excellent coverage of the Echo II spacecraft operation permitting a detailed evaluation both of prototype satellite and orbital satellite performance.

It was successful in demonstrating the use of real time TV in monitoring spacecraft operation in outer space and shows that TV can be applied to other types of space operations requiring real time visual observation.

Much of the success of this system was due to the very careful study and preparation made to recognize and understand the problems before designing a solution.

G65-10068 c. 2.

THE APPLICATION OF A BEACON TELEMETRY SYSTEM FOR MEASURING ORBITAL PERFORMANCE OF THE ECHO II SATELLITE

by Norman L. Martin and Harold S. Horiuchi
Goddard Space Flight Center

INTRODUCTION

The Echo I satellite launched in 1960 carried two radio beacons on the structure for the purpose of acquiring and tracking the satellite as it orbited the earth. Although these beacons provided tracking information over a period of time suitable for establishing the orbit of the satellite, they ceased operation within a few weeks after launch.

In the process of establishing the design configuration of the Echo II satellite, consideration was given to the possible use of radio beacons which in addition to tracking data would provide information regarding certain operational aspects of the satellite for a minimum period of one year.

SYSTEM REQUIREMENTS

The Echo II satellite was constructed from a three layer laminate material of aluminum foil and plastic mylar, designed to provide increased rigidity requirements over that of its predecessor Echo I. Figure 1 illustrates the type of material from which the two satellites were constructed.

The basic design of the Echo II structure was such that it was necessary to pressurize the sphere to an effective skin stress level above the yield point of the aluminum foil in order to achieve and maintain the desired structural shape and rigidity characteristics. Therefore, it was highly desirable that information regarding the relative pressures achieved within the orbiting structure be provided for evaluation of spacecraft operation. It was anticipated that the internal pressure to be monitored would range from a minimum of 10^{-5} mm to a maximum of 0.5 mm of mercury (Hg).

In order to provide information for evaluating some of the environmental effects upon the inflation, pressurization and structural behavior of the satellite, it was also desirable to measure the satellite skin temperature at certain points on the structure. This information was particularly important during the orbit deployment phase of the satellite since the inflation of the sphere at deployment

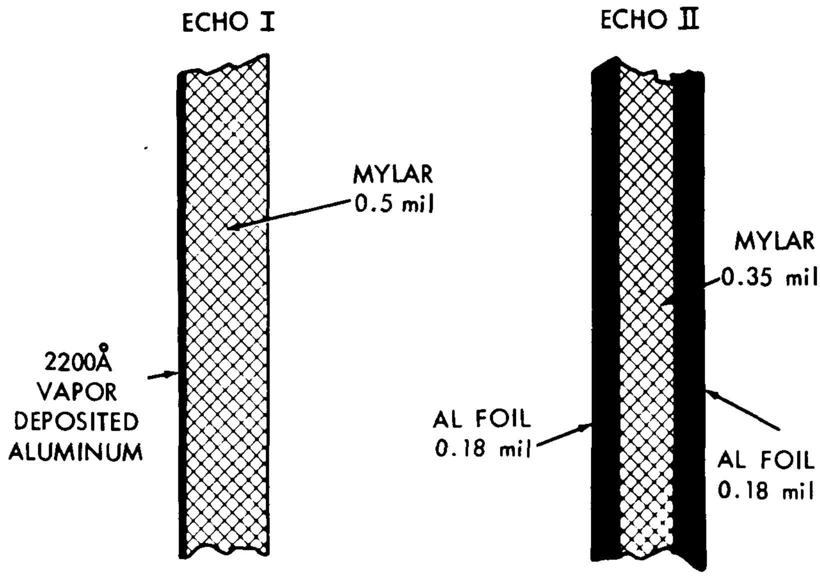


Figure 1. Cross-Sections of Echo I and Echo II Material

was to take place in a matter of minutes. A TM system having very sensitive sensors with very short time constants was required. The telemetry system was required to measure skin temperatures between minus 120 degrees and plus 150 degrees Centigrade.

Lastly, it was necessary that a means for the very early establishment of a precise orbital parameter be provided in order that the planned Satellite Experiments could begin during the early lifetime of the satellite.

In meeting these operational requirements for pressure, temperature and orbital data, it was necessary that several physical requirements be satisfied such as configuration, size and weight. The configuration and size were important in that the beacon had to conform to the overall payload packaging technique, in which the sphere was to be folded accordian-fashion into the canister. The configuration was further important in that during the unfolding and deployment of the satellite sphere, there was to be a minimum of localized stresses imposed on the satellite surface. The weight was limited by the overall limit of the payload package and also because of the need to limit mass concentration on the sphere surface.

DESCRIPTION OF ECHO II TELEMETRY BEACON

Physical Description

The telemetry beacon employed on the Echo II satellite was 13.5 inches square and 0.7 inch thick. The components were mounted on etched circuitry and encapsulated in foam plastic. The beacon excluding the battery packs, weighed less than 3 pounds. The weight of a complete beacon system consisting of a transmitter, two battery packs and four solar cell panels and interconnecting cables was approximately six pounds.

Two independent beacon systems were mounted 180 degrees apart on the mechanical equator of Echo II. The solar cell panels were mounted at the corners of rectangle 25" × 78" with the transmitter located at the center. This is illustrated in Figure 2, which is a photograph of a beacon system being installed on the satellite structure prior to its being placed in the canister. The purpose of

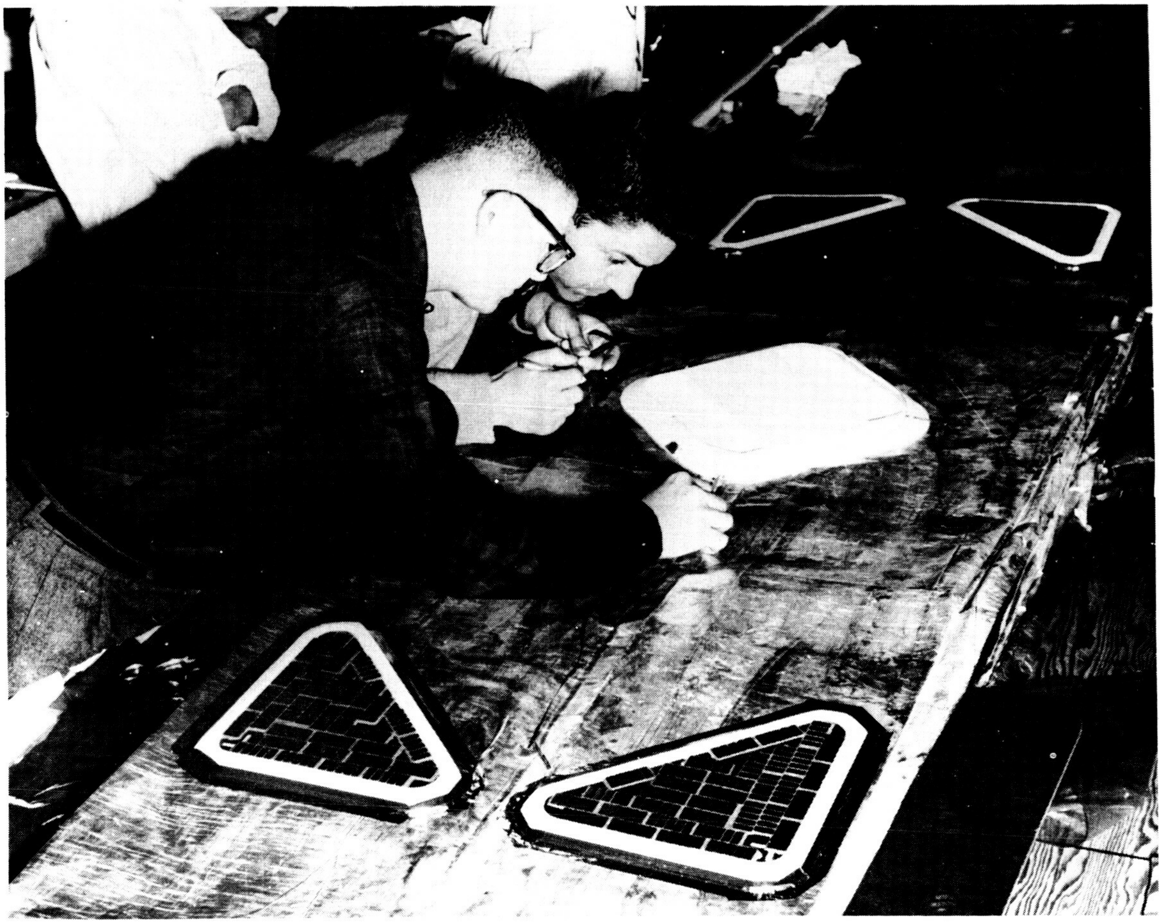


Figure 2. Installation of Echo II Beacon

the redundant (dual beacon) systems was to obtain telemetry coverage from at least one beacon during each orbital period. Both the transmitter and the solar panels were attached to the satellite with pressure sensitive adhesive tapes. The sphere was then packed inside its canister as indicated in Figure 3.

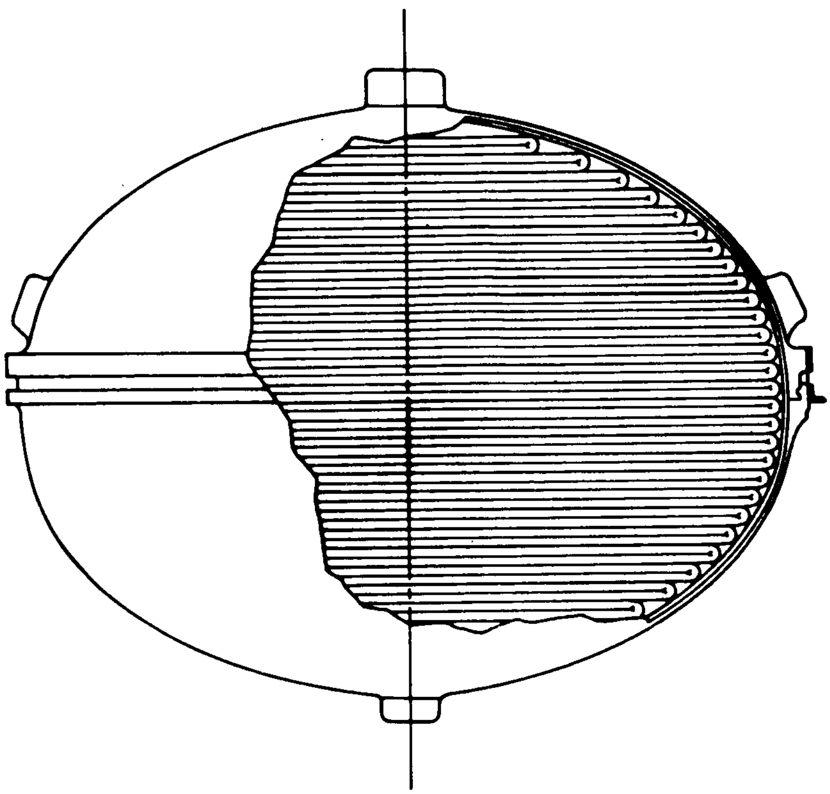


Figure 3. Echo II Satellite as Packed in Canister

Electrical Description - General

The carrier frequencies assigned to the beacon transmitters were 136.020 mcs and 136.170 mcs, with a tolerance of ±0.0005% at 25° C and a stability limit of ±0.002% from the set frequency over an environmental temperature range of -10 to +60°C and under pressures encountered in space (10^{-5} mm of Hg or less).

The transmitter was amplitude modulated with three sinusoidal subcarrier frequencies as indicated in the block diagram of Figure 4 (S.C.O. #'s 1, 2, and 3). The subcarriers were within the IRIG 2, 3 and 4 channels having respective center frequencies of 560, 730 and 960 cps with a standard IRIG deviation of ±7.5%.

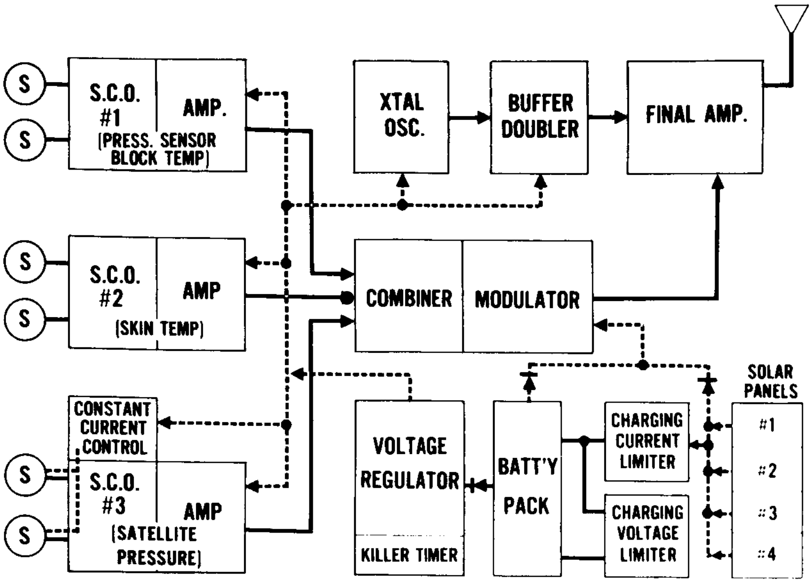


Figure 4. Block Diagram of Echo II Beacon

The antenna was a quarter wave monopole made of spring wire. Until the satellite was injected into space and inflated, the antenna was folded and held within a groove on the side of the transmitter by the folds of the satellite. Upon inflation the antenna was erected and assumed a position normal to the surface of the satellite.

As required in the specification, the effective radiated power of each transmitter was greater than 34 milliwatts at continuous operation. The power supply for the beacon transmitter consisted of two battery packs, each of which contains eight nickel-cadmium cells that were connected in series. The packs were also connected in series and represent an open circuit fully charged supply of approximately 20 volts.

In order to obtain the highest possible degree of continuous operation, the beacons had an auxiliary power source made up of a number of solar cells in a series-parallel connection. Each of the four panels was capable of delivering approximately 4 watts maximum; total for the 4 panels being 16 watts. This was a computed figure using 0.140 watt/cm^2 as the solar constant and a cell efficiency of 10.5% at air mass zero. The operating power requirement for the transmitter was 2 watts nominal. Allowing for losses such as reflection and transmission, random cell failures, intensity variation and uncertainty, etc., the available power from the 4 panels was estimated at slightly better than 12 watts, approximately six times the nominal power requirement.

Electrical Description - Transmitter

A schematic diagram of the beacon is presented in Figure 5. The RF transmitter consisted of a crystal oscillator, a buffer-doubler and a final amplifier. The oscillator frequency of approximately 68 megacycles, was obtained from the fifth overtone of the crystal frequency. Both the crystal oscillator and the buffer-doubler operated from a voltage regulated dc supply (at 19.2 volts), while the final amplifier received its dc power from the modulator stage in a series feed system. Voltage regulation of the oscillator and buffer supplies eliminated the de-tuning effect which would be caused by transistor collector voltage changes. The buffer stage also aided in maintaining oscillator stability by isolating the effects of coupled capacitance changes created by load changes in the final amplifier.

Pre-launch tests made on the transmitter indicated that it was quite stable with changes in environment. It was found that the antenna position relative to a ground plane had a negligible effect upon the oscillator frequency. Moreover, when the d.c. collector voltage of the final amplifier was varied over a range of ±10% in excess of the maximum value encountered in the peak-to-peak modulation voltage, it was found that the oscillator frequency modulation due to carrier modulation would be less than 100 cycles at the carrier frequency of 136 megacycles.

The RF carrier outputs of the two flight beacons (serial numbers 701 and 702) as measured prior to launch were 39 and 34 milliwatts, respectively.

Electrical Description - Subcarrier System

Intelligence to be telemetered consisted of three parameters: a) internal pressure; b) satellite skin temperature; and c) beacon temperature. These parameters were to be monitored by their respective sensors, converted to subcarrier frequencies in the assigned IRIG channels, and the signal fed through a combiner-modulator to the final amplifier.

The internal pressure to be monitored ranged from a minimum of less than 1 micron of Hg to a maximum of 500 microns. The skin temperature to be monitored ranged from -120° C to +150° C. and the beacon temperature expected in the orbital environment ranged from -10° C to +60° C.

All three parameters were monitored with temperature sensitive resistance elements. The variable resistance elements (matched pairs) were used as the frequency control arms of a balanced Wien bridge oscillator circuit. The three subcarrier oscillators were fed through their respective amplifier and emitter follower circuits to a common combiner-modulator circuit. The subcarrier circuits also operated off a voltage regulated supply. The modulator power supply, however, was not regulated since the modulator circuit contained both ac and dc feedback loops and the power delivered to the final amplifier would be fairly stable.

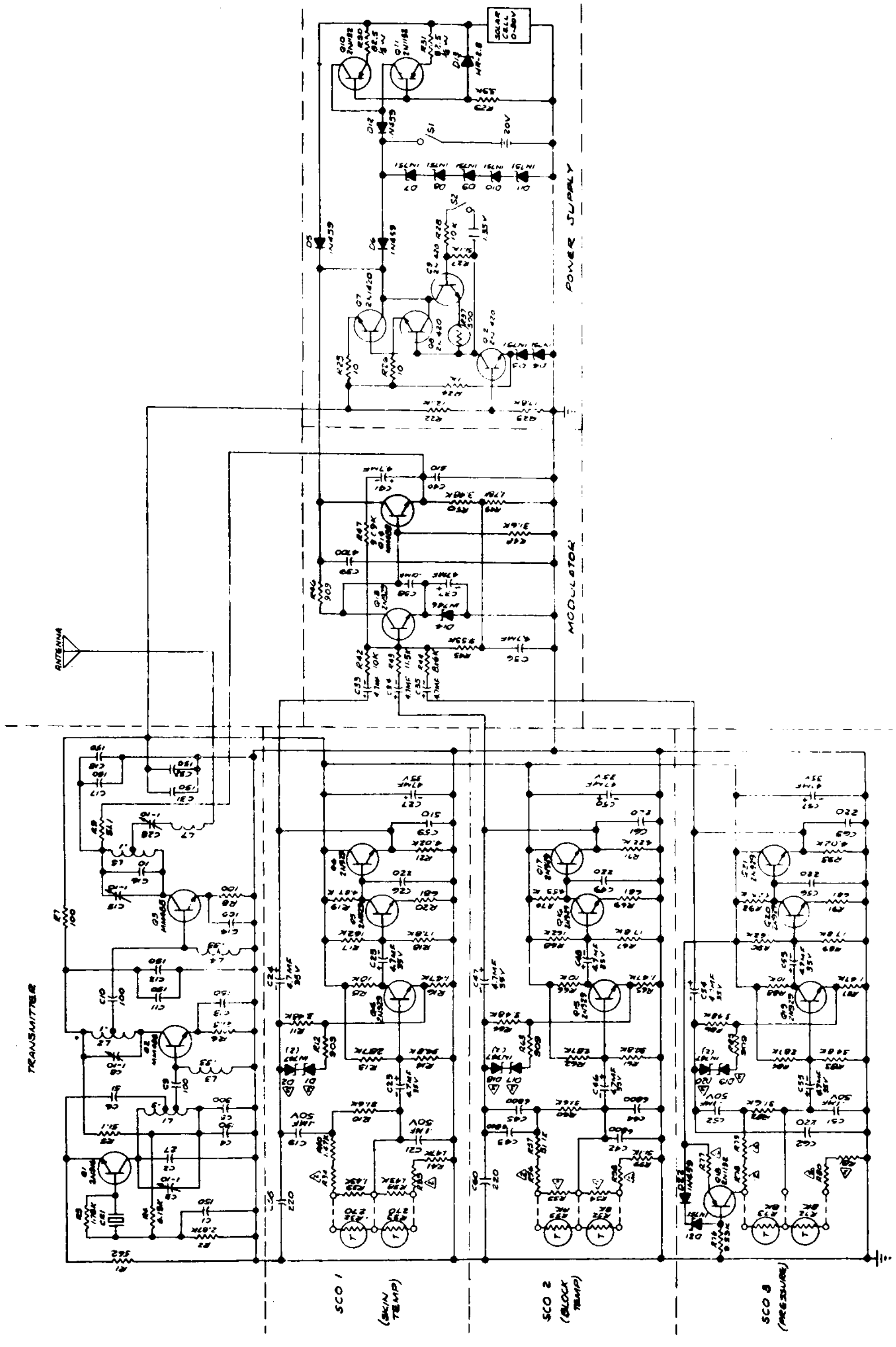


Figure 5. Schematic Diagram of Echo II Beacon

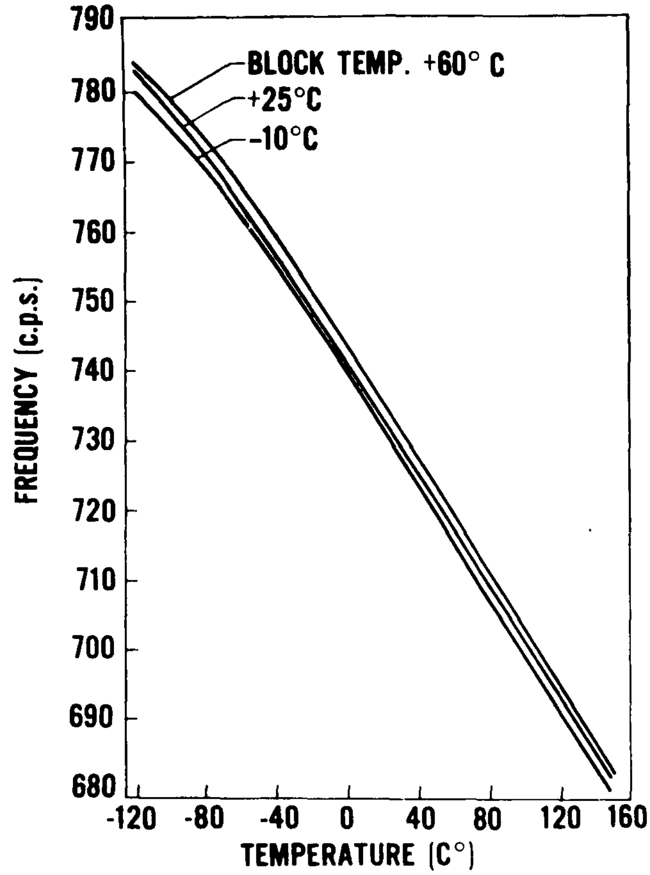


Figure 6. Skin Temperature Calibration Curves

Because of the nature of the tracking filters which have their bandwidths fixed at a certain percentage of the center frequency, the de-modulated telemetry signal-to-noise ratio at the tracking receiver would vary if all subcarriers were transmitted at an equal percentage of the modulation. Therefore, a weighted modulation scheme in the form of a resistor-adder was employed at the input to the combiner stage. The overall modulation level of the transmitter was about 40%.

Figure 6 is a typical calibration curve used to determine satellite skin temperature. Note the proximity of the three curves, indicating the temperature sensitivity of the subcarrier oscillator (S.C.O. #1 - see Figures 4 and 5).

Pressure Sensing System

As previously mentioned, the pressure sensor was required to be capable of covering a range from less than one micron to 500 microns of mercury. The subcarrier bandwidth available (IRIG 4) was 144 cycles, roughly 3.5 microns per cycle. Secondly, the sensing time constant was required to be very short so that the actual inflation process during orbital deployment could be monitored faithfully. The third requirement was that the sensing system design be compatible with any gas that would be selected for the controlled inflation system.

The first two requirements were satisfied by frequency control of the Wien bridge subcarrier oscillator and by the use of short time constant, low heat capacity, sensitive thermistor beads as the sensing elements. The use of thermistors was suggested by J. Ainsworth and A. P. Flanick of GSFC.[1] The authors showed that an accuracy of 1.5% could be obtained over a pressure range from 10^{-2} to 10 millimeters of mercury, that a thermistor of a high negative temperature coefficient was required and that the thermistor had to be operated at a relatively high reference temperature. The actual sensing system finally employed in the Echo beacon was a compromise which considered the various possible methods including the Ainsworth-Flanick system.

Two fine-bead type thermistors were mounted in a cavity within a magnesium block as illustrated in Figure 7. A small hole which was provided to allow gas moledules to enter the cavity was shielded to protect the thermistors from direct thermal radiation. The thermistors were heated with a constant dc current from the regulated supply line to provide the reference temperature. The loss of heat

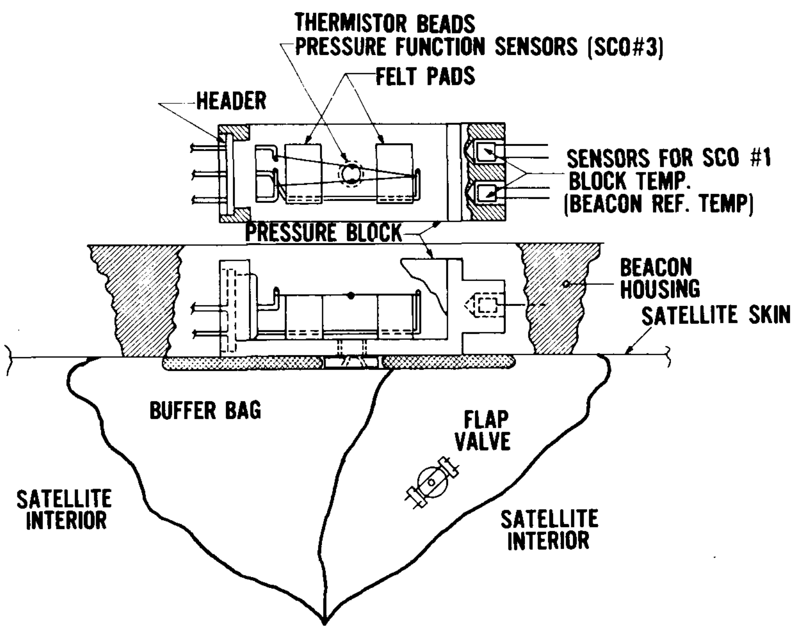


Figure 7. Sketch of Echo II Pressure Sensing System

from the thermistor beads under bombardment by gas particles created a change in the resistance, thus determining the subcarrier frequency. The degree of cooling of the beads was dependent on the mean molecular mass as well as the mean free path of the gas molecules; the higher the pressure the greater the cooling effect.

The third requirement (compatibility with any inflatant gas) was necessary because calibration of the sensing system could not be delayed pending determination of the inflatant in the final system design. Therefore it was decided to design a sensing system compatible with any gas by calibrating the sensors with air and using a buffer chamber to isolate the sensor from the inflating gas. This chamber was constructed of polyethylene film in the shape of a tetrahedron. The sensor block cavity was exposed to the interior of the buffer chamber which was attached to the underside of the beacon on the inside of the satellite.

The buffer chamber was fitted with a one way flap valve that permitted air to pass out of the chamber but did not permit the gas to leak in. Sufficient residual air molecules were deliberately allowed to remain in the buffer chamber and sensor cavity after folding and evacuating the canister to one millimeter of mercury. These molecules were then available to collide with the thermistors in the sensor cavity after the satellite had been inflated. In operation, as the satellite's internal pressure increased, the buffer chamber "deflated" until the pressure inside and outside the chamber was equal.

In the Ainsworth-Flanick scheme, the heat transfer from the thermistor to the cavity wall was used as the basis of pressure calibration. Since the environmental temperature to be experienced by Echo could not be completely controlled, it was necessary to let the cavity block temperature work together with the thermistor resistance change. That is, in the calibration of the pressure sensors the entire beacon (including the cavity block) was soaked at several levels of temperature, in each instance holding constant the current which heated the thermistors. Two other thermistors located in the sensor block then served as the reference temperature sensors working through the third subcarrier channel (IRIG 2). The variation in the frequency of the pressure subcarrier was then monitored as the pressure was changed at each block temperature.

Figure 8 illustrates a typical block temperature calibration curve for use in obtaining the satellite pressure. Tests had indicated that the temperature rise of the block would not be greater than 25 degrees C, under the anticipated operational conditions. Therefore the calibration range of the reference temperature from -10°C to a plus 60 degrees C was quite adequate and was well within the capabilities of the subcarrier frequency range of 80 cycles.

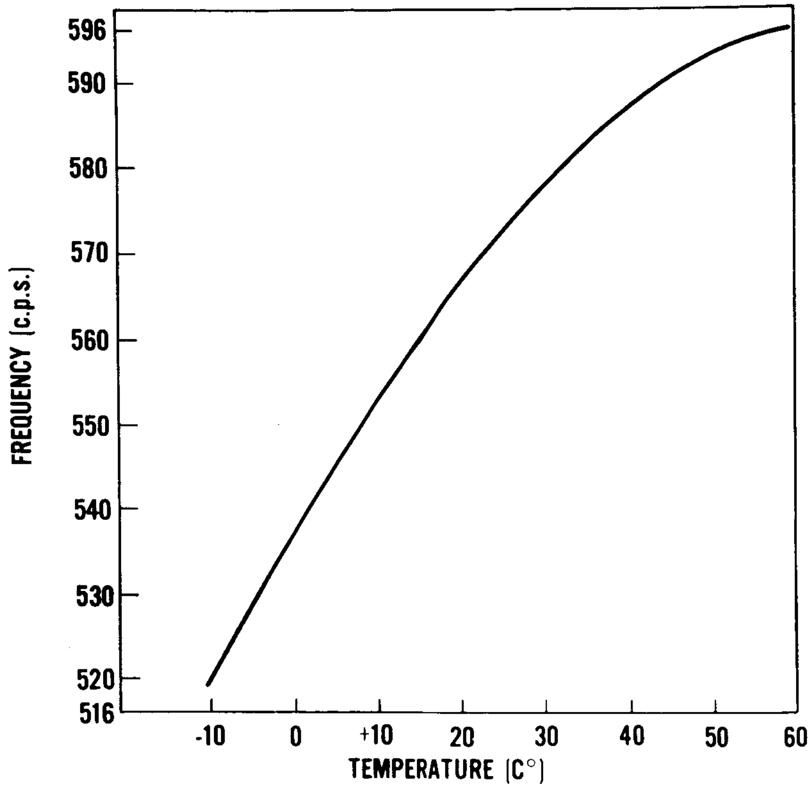


Figure 8. Beacon Block Reference Temperature Calibration Curve

Figure 9 is a typical pressure calibration curve and shows the relation between the reference block temperature and the associated temperature curves for obtaining pressure.

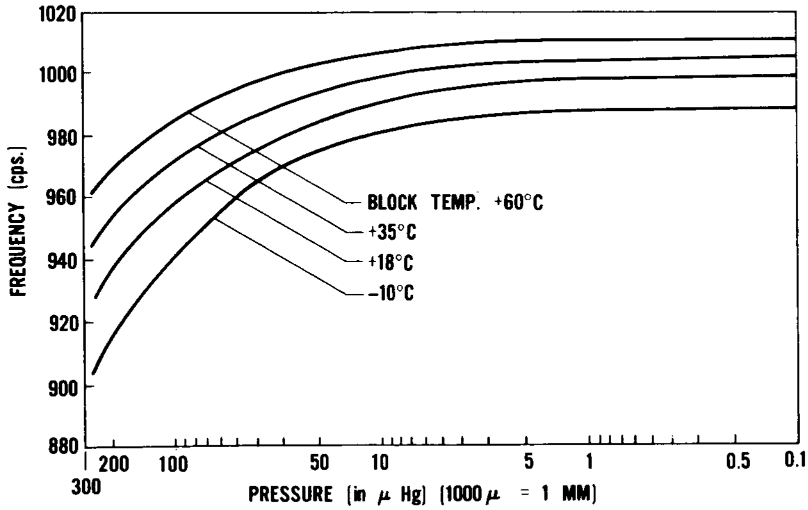


Figure 9. Pressure Calibration Curves

BEACON PERFORMANCE AND DATA ANALYSIS

The pressure and temperature history of the Echo II satellite during the initial inflation stage is illustrated in Figure 10. The data presented in Figure 12 is for two orbits or approximately three and one half hours of flight after satellite deployment. The dashed portions of the curves are estimated and result from a lack of data due to the separation distance between the tracking stations, which precluded continuous orbital coverage.

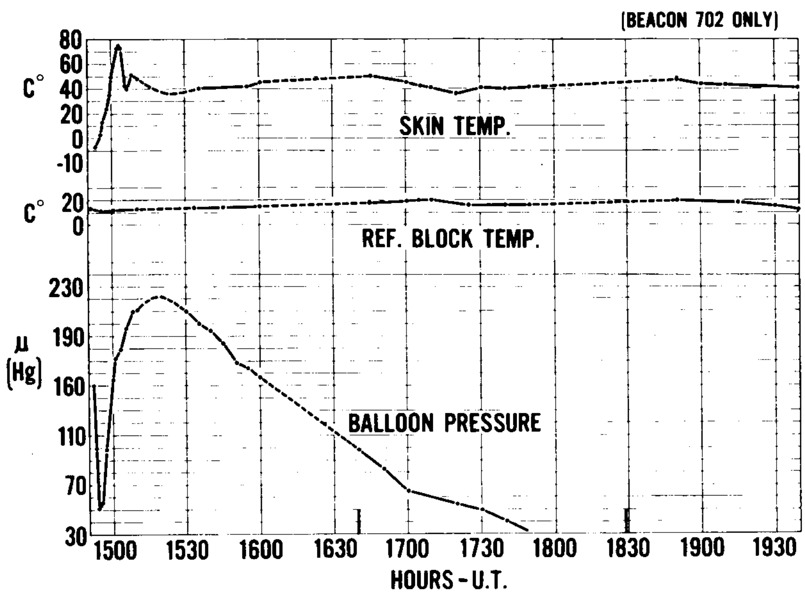


Figure 10. Beacon Telemetry Data Echo II Launch Jan. 25, 1965

The temperatures of the satellite skin and of the beacon, have been monitored since launch and the average skin temperature of Echo II during the first year in orbit has been approximately 50 degrees C. Satellite skin temperatures as high as 90 degrees C have been recorded while the lowest temperature recorded was minus 115 degrees C, occurring just moments after the satellite emerged from the earth's shadow and the beacons resumed operation. This low temperature is at the lower limit of the subcarrier calibration.

The telemetry beacons have provided certain other additional information. One of considerable interest is the rotation speed of the satellite, while another is the location of the satellite spin axis and its attitude. After initial spinup during the first orbit, the rotation speed has been gradually decreasing. Figure 11 shows the rotation period in seconds versus time. The smooth curve represents the mean daily spin periods. Since the time span of the curve has been compressed considerably, it appears as if the spin period has changed drastically in one year. However, at the end of one year the rotation period only increased from a minimum of about 93 seconds to 116 seconds and by the end of June 1965, had increased to approximately 120 seconds. The average rate of increase in the spin period during the first year was about 0.06 second per day. Recorded short

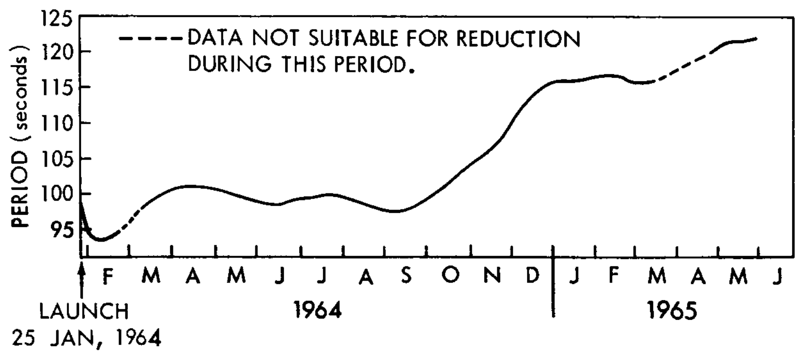


Figure 11. Echo II Rotation Period Versus Time in Orbit

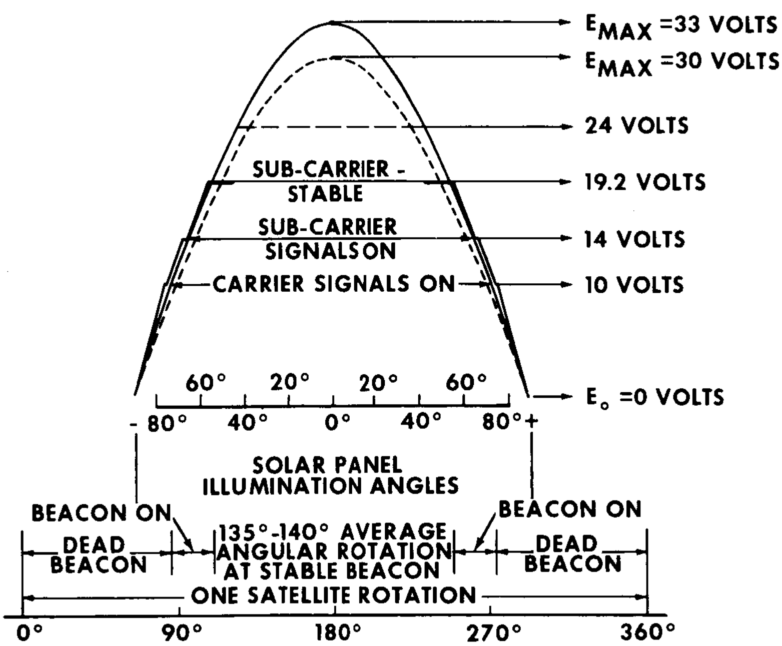


Figure 12. Echo II Rotation Versus Beacon Operating Voltage

term perturbations have been greater than this amount. The station to station variations within an orbit have been about 1/4 second or less and the orbit to orbit variations at a given station have been within one-half of a second. The undulations in the curve are unexplainable at this time but are believed to be related to the effects of solar pressure and the sun orbit plane angle. A rather detailed study has been made regarding the possible causes of the Echo II satellite spin[2] and the results of this study will be included in the project's final report.

The unexpected high spin rate of the Echo II satellite resulted in an extensive examination of the beacon data. This data was the major source for evaluating the satellite spin history. Initially the rotation period of the satellite was obtained by using the AGC record which appears as a low amplitude, long period, slightly irregular sinewave on the strip chart recording. The accuracy of the rotation period obtained by measuring between the estimated centers of the AGC maxima and minima was ±5 seconds. This tolerance was not sufficient for the required spin analysis and the following procedure was deduced which resulted in the determination of a spin period within 0.25 second.

The supply voltage began to vary soon after orbit deployment because the battery voltage dropped below the regulation level and the battery capacity dropped below the recovery point, with the result that the beacon operation became completely dependent on solar cell power. The rotation of the satellite also caused the solar power supply voltage to vary.

The effects of the satellite rotation on the solar cell power supplies was then examined. The maximum output possible from a solar cell at a given angle of incidence varies primarily with the load, solar constant, cell efficiency and deterioration rate. On a short term basis, the maximum output from the Echo II solar panels, therefore, depends on the minimum angle of incidence reached during any rotation period. Finally, the overall beacon stability depends on the supply voltage from the solar panels, which in turn is a function of the solar incidence angle. Figure 12 shows the relationship between voltage, beacon performance and satellite rotation. The subcarrier stability is affected first by the power supply changes. For example, the temperature sensor channels 2 and 3 changes two or three cycles when the supply voltage drops below the regulation level of 19.2 volts. The frequency would then hold there as long as the supply voltage remained above 14 volts (also see Figure 13). The subcarriers cease to operate when the supply voltage dropped below 14 volts. On the other hand the pressure sensor channel 4 which contained the constant current heating device would continue to drift in frequency until the supply voltage dropped below 14 volts at which point it would also cease to operate. The carrier oscillator would shift frequency with supply voltage also, but it would not stop oscillating until the voltage dropped to about 10 volts or less. Figure 14 shows a typical carrier shift

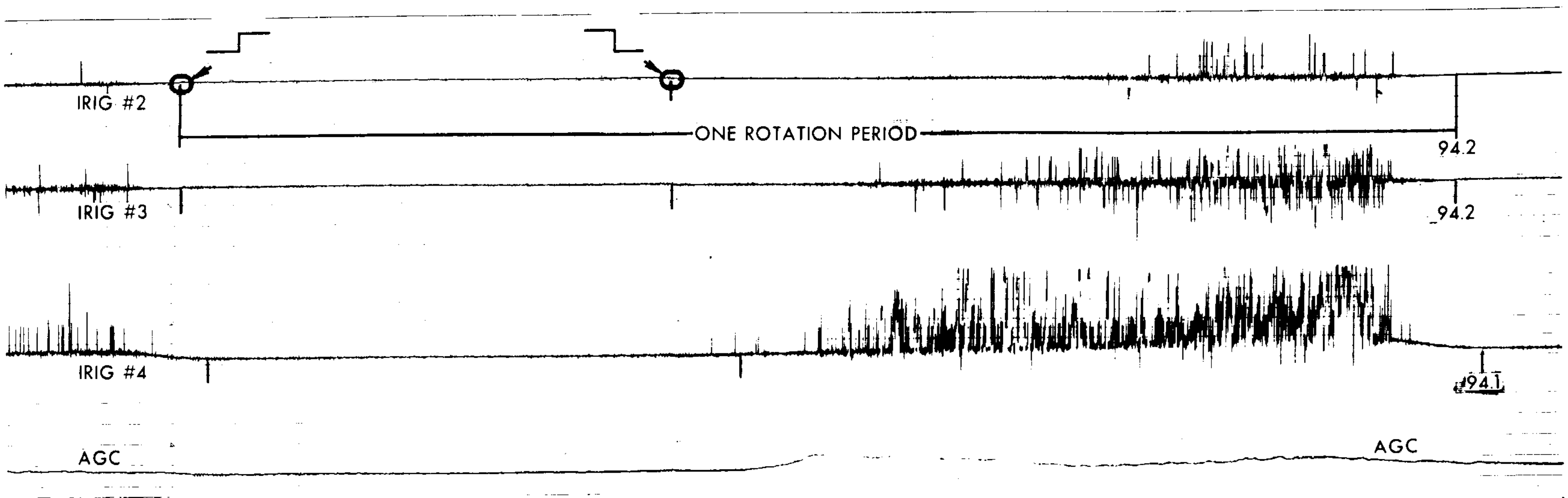


Figure 13. Typical Subcarrier Data

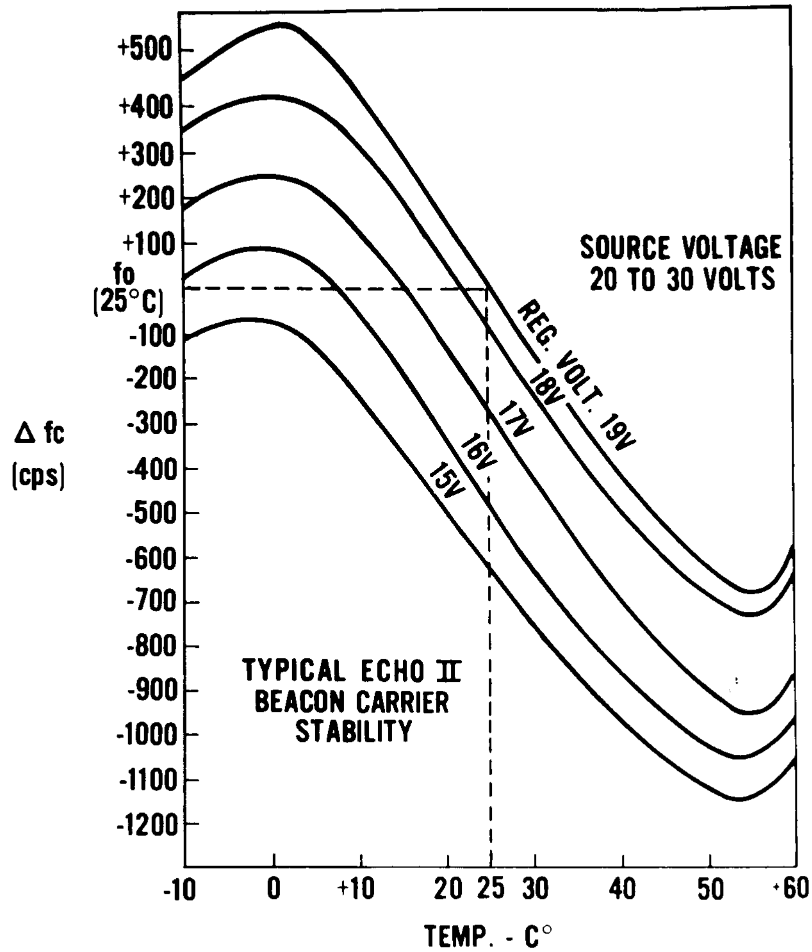


Figure 14. Frequency Deviation Versus Beacon Temperature and Supply Voltage

as functions of beacon temperature and supply voltage. In the flight units the carrier frequency remained within the receiver bandwidth and would continue to be received by the tracking stations but without any subcarrier signal during part of a rotation period and during part(s) of an entire pass at times. Normally one would depend on the carrier level or the AGC level to determine the spin rate but in this instance, it was more accurate to use the subcarrier frequency shifts (Figure 13) since they were purely dependent on the solar panel voltage output which in turn is a function of the incident illumination angle only. Data have been obtained during some of the passes over certain stations in which the subcarrier from one beacon (#702) is present continuously for three to four satellite rotations, while the other beacon (#701) fades in and out with the rotation period.

The stability of the beacon with adequate operating supply voltage is attested to by the near superpositioning of the two curves in Figure 15. These curves illustrate the doppler shift versus time as the satellite passed over the Blossom Point, Maryland tracking station. The smooth curve is the predicted doppler shift of the beacon for this pass. Several interesting events can be seen. First, there is the relative stability of the carriers that occur periodically during the pass. Next, there is the repetitive sharp dips in the doppler shift, which in this case occurs at 100 second intervals. Finally, there are the signal drop-outs (dotted) as the antenna pattern passed out of range and/or the solar power dropped to the point of signal dropout.

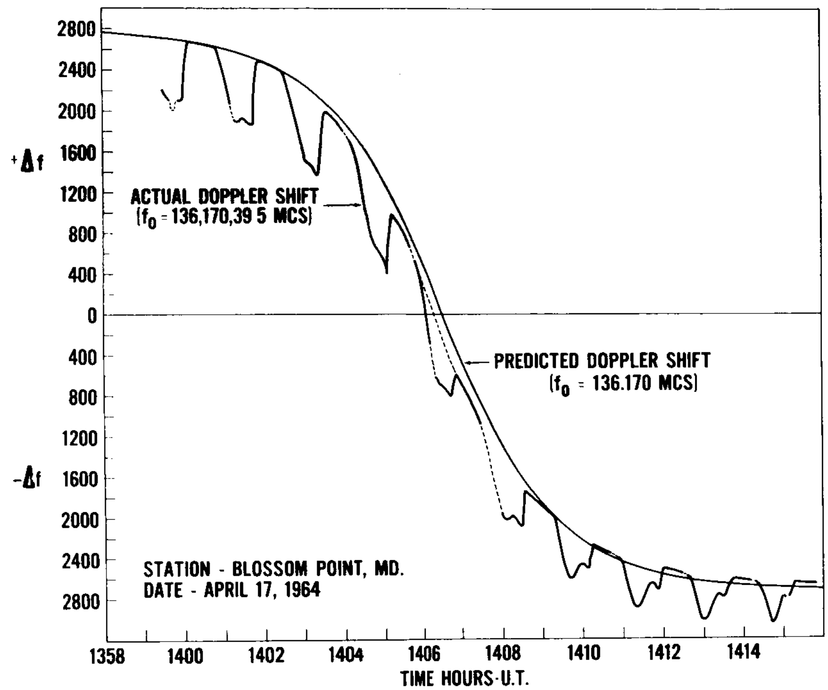


Figure 15. Typical Doppler Shift Curve of Echo II Telemetry Beacon

The same frequency shifts in the subcarriers which provided the spin period information also provided the primary information for determining the spin axis of the satellite (see Figure 13). The time between the sharp steps (circled) is the fractional period of one satellite rotation during which the entire beacon is operating normally from the regulated supply voltage. The duration of this stable period, in terms of percent of rotation cycle, has varied throughout the monitoring period, with beacon 702 consistently showing longer stable periods than the other, 701. Other data, such as continuous reception of beacon 702 for durations up to 4 revolutions and fading in and out of 701 during the same period, have led to the conclusion that 702 is located in such a position that it is operating for the most part from power generated by the earth's reflection and it can thus receive continuous reflected illumination for long periods while 701, located diametrically opposite, receives direct but periodic illumination from the sun only.

Examination of the telemetry data and evaluation of the beacon performance led to several interesting observations. The first was that from any given tracking station almost identical data can be received every 13 passes or 24 hours for periods up to five days; however, the subcarrier signatures were different from station to station in a given pass. Analysis of these observations indicate that the satellite is spin stabilized and any perturbation of the spin axis, if present, is virtually unnoticeable over a several day period. Nearly identical signatures have been obtained at periodic intervals on a long term basis at a given station, the only difference from the above case being the duration of the stable beacon operating period per rotation.

A relationship between the solar incidence angles and the stable beacon operating periods as a function of the location of the beacon with respect to the spin axis was then computed analytically. The extensive hand processing of the strip chart recordings has limited the number of positive spin axis determinations. However, by correlating the reduced data, it has been determined that the spin axis is shifting or precessing on a long term basis. The spin axis describes an approximately conical surface with the declination shifting ±5% about a mean declination angle of 55° north. The right ascension is shifting over a range of about 60° to 70° at a rate of approximately one degree per day. The mean position of right ascension has been indeterminate to date.

The spin axis has also remained approximately fixed with respect to the satellite with the beacons located 55° to 60° from the spin axis of the satellite and with the pole caps of the satellite lying in a plane normal to the line connecting the beacons.

SUMMARY AND CONCLUSIONS

The performance of the beacon transmitters has been highly satisfactory and well beyond the expectations placed on them. Satellite skin temperatures as low as minus 110 degrees C have been recorded within minutes after the satellite emerged from the earth's shadow. The maximum temperature recorded was approximately 90 degrees C. Since the transmission is dependent upon solar illumination, the transmitter does not operate when it is in eclipse and consequently the lowest temperature experienced by the transmitter is indeterminate. Both the RF and the subcarrier sections of the beacons have performed excellently in the exposed extreme temperature range environment.

The beacon telemetry system has provided excellent temperature and pressure data. In addition this system was the only meaningful source of data regarding the spin history of the satellite. The beacons were not specifically designed for this purpose, since the high satellite spin rate was unanticipated. An extensive study of the beacon carrier and subcarrier dependency on their solar cell power supplies was necessary before the spin axis behavior could be interpreted from the telemetry data. The primary data used in the analysis are the frequency shifts in the subcarrier channels resulting from the changing incident angle of illumination on the solar panels caused by the satellite spin.

An initial spin period of 110 ± 5 seconds was established by the end of the first orbit. The spin period decreased to a minimum of 93.5 ± 1 seconds 15 days after launch and has slowly increased to a period of approximately 120 seconds at the present time.

Positive determination of the satellite spin axis in a celestial coordinate system is possible by analysis of the beacon data; however, the number of finite determinations are restricted due to the numerous requirements that must be met in the available data.

The satellite has been determined to be essentially spin stabilized with minor coning of the spin axis and with a slow drift of the right ascension of the spin axis.

The beacon circuitry includes a mercury cell cutoff circuit designed to turn off beacon transmission after approximately one year. The lack of subcarrier signals on one beacon indicates that the cutoff is approaching and Echo II will soon be silent.

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1. NASA TN D-504, " A Thermistor Pressure Gage" by J. Ainsworth and A. P. Flanick (GSFC), Nov. 1960.

2. NASA/GSFC Publication "Post Launch Analysis Final Report Passive Communication Satellite Echo II" dated September 1964.

G65-10069 c. 2.

RESULTS OF COMMUNICATION EXPERIMENTS CONDUCTED WITH THE ECHO II SATELLITE

by Wilbur C. Nyberg, Goddard Space Flight Center

SUMMARY

Communication experiments were conducted with the Echo II satellite beginning shortly after its launch from the Western Test Range in January 1964. The objectives of the experiments were to determine the capability of the Echo II satellite as a passive communications device, and to provide information about the shape and surface characteristics of the satellite as a function of time. The tests conducted included: Measurement of the Signal Level, Coherent Bandwidth Test, Facsimile Transmission, and Voice and Music Transmission. The major participants in the program were the Naval Research Laboratory near Washington, D. C., Collins Radio Company at Dallas, Texas and the Ohio State University at Columbus, Ohio.

The tests were quite successful and results indicate that the satellite's shape and surface characteristics did not change appreciably over the test period. The tests have demonstrated that the satellite provides a very satisfactory reflector for use in passive satellite communication systems, particularly when frequency diversity is employed.

Test results indicate an average scattering cross section for Echo II of 30.2 db or approximately 1 db below that for a theoretically perfect 135 foot diameter sphere. Test results also indicate that Echo II has a coherent bandwidth capability in excess of 12 Mcs and that frequency diversity techniques are effective with a 190 Mcs (or greater) separation of carriers. Good performance of the Echo II circuit was demonstrated on facsimile transmission and voice and music transmission.

The limited experiments conducted with Echo I indicate that in spite of its apparent surface deterioration the satellite continues to provide a useful communications medium.

INTRODUCTION AND OBJECTIVES

The first passive satellite, Echo I, was launched from the Eastern Test Range in August 1960. A variety of experiments under NASA sponsorship were conducted via the satellite between August 1960 and March 1961 by the Bell Telephone Laboratories, Jet Propulsion Laboratory and the Naval Research Laboratory.

The experiments included voice and music transmissions and the determination of received power from the satellite. In general, the communications performance of all links was very near that initially predicted, and the feasibility of using such satellites as passive relays in passive communications systems was demonstrated.

During the early lifetime of the satellite, prior to the loss of internal pressure, the reflected signal was very steady, showing only a small variation in signal strength. However, within two weeks after launch, variations in the reflected signals increased noticeably. These changes in signal variation were attributed to a corresponding change in the satellite's structural surface caused by the loss in satellite pressure and the effect of the space environment. This degradation in performance of the Echo I satellite indicated that more rigid satellite structures were required if long useful lifetimes were to be achieved. Project Echo II was established for this purpose.

The Echo II satellite, designed to provide improved rigidity characteristics over its predecessor, Echo I, was launched from the Western Test Range in January 1964. The satellite, 135 feet in diameter, was placed in a near circular orbit of approximately 600 nautical miles at an inclination of 81.5 degrees.

Communication experiments were conducted with the satellite throughout the calendar year 1964. The objectives of the experiment were:

- To determine the capability of the Echo II satellite as a passive communications device

- To provide information about the shape and surface characteristics of the satellite as a function of time

The results of the experiments will provide information to aid the designer of communication systems utilizing passive satellites as well as designers of other types of space inflatable structures.

EXPERIMENT PARTICIPANTS

Three stations were originally selected to be major participants in the experiments program. These stations were located at the Naval Research Laboratory (NRL) near Washington, D. C., Collins Radio Company at Dallas (CRC); and the Navy Electronics Laboratory at San Diego (NEL). They were selected on the basis of their availability. In addition, a maximum number of mutually visible satellite passes would result by virtue of their locations.

The Navy Electronics Laboratory experienced technical difficulties with its antenna system and as a result, its participation in the program was quite limited. Because of this limited participation in the experiments, the results obtained by the NEL facility will not be discussed in this paper.

As the test program continued, NRL's participation became limited by other commitments and by restricted optical visibility of the satellite because of eclipse. At this time, Ohio State University (OSU) Columbus, Ohio with an automatic tracking capability, commenced participation in the program.

In the normal mode of operation, as illustrated in Figure 1, the Collins facility illuminated the Echo II satellite at either 2260 Mc or 2380 Mc, utilizing a solid surface, 60 foot parabolic antenna and a 10 kilowatt transmitter. The signal, reflected from the satellite, was received by a 60 foot parabolic antenna at the NRL facility and by four 30 foot parabolic antennas at the (OSU) facility in Columbus.

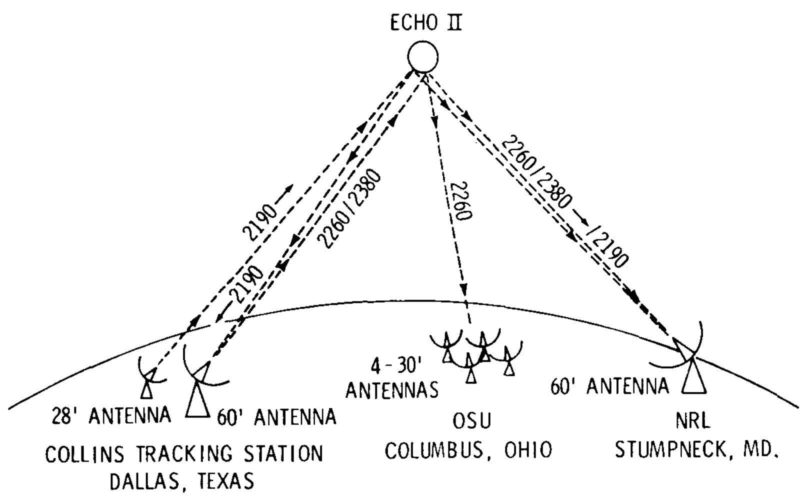


Figure 1. Circuit Configuration, Echo II Communication Experiments, Dallas – Columbus – Stump Neck

To provide accurate pointing of the 60 foot antenna at Dallas, a radar automatic tracking system operating at 2190 Mc, was employed. This system consisted of a 28 foot parabolic antenna with a 10 kilowatt transmitter for illumination at 2190 Mc, together with the 60 foot antenna which was equipped with an amplitude monopulse feed and phase-locked tracking receiver to receive the radar signals. An automatic acquisition system based on the satellite position predictions, furnished by Goddard Space Flight Center, (G.S.F.C.) was used to acquire the satellite.

The NRL antenna was program pointed by means of a digital drive tape derived from predicted look angles. An optical tracker was used to correct errors in the drive tape when the satellite was optically visible. When visibility was obscured by weather or by eclipse, the signal was peaked by scanning with the antenna. Because of slight inaccuracies in the predictions, most of the experiments between Collins and NRL were conducted at night so that signal fluctuations caused by mispointing of the antenna could be minimized through the use of the optical tracker. The NRL receiver system utilized a low noise Travelling Wave Tube and a phaselocked i.f. loop at 60 Mc to provide high sensitivity. Modified R-390A/URR communication receivers served as the primary envelope demodulators in the experiments. During the space diversity experiment, NRL used a 10 kw transmitter to transmit to Collins on 2380 Mcs.

The OSU station utilized four 30 foot diameter parabolic antennas and parametric amplifiers feeding phase lock receivers with phase locked demodulators. A monopulse automatic tracking system was used for pointing the antennas.

All three facilities were equipped with a variety of strip chart and magnetic tape recorders for recording the experimental data. Both the Collins and NRL facilities were also equipped with boresight cameras so that any pointing errors could be accurately determined.

Data from the Collins facility and from the NRL facility were reduced, primarily by the Collins Radio Company under contract to Goddard. Reduction of the data from the facsimile experiments as well as the recording of the original master facsimile magnetic tape was done at NRL. The OSU station reduced and analyzed their own data and the results have been published in a series of OSU reports.

EXPERIMENT PLAN

Prior to launch, a detailed Communication Experiment Plan[1] was prepared, outlining the objectives and the planned method of implementation.

As stated previously, this plan was designed to provide information regarding:

- The capability of the Echo II satellite as a passive communications device.
- The shape and surface characteristics of the satellite as a function of time.

Included in the Experiments Plan were the following tests:

- Signal Level Measurements Test
- Coherent Bandwidth Measurements
- Facsimile Transmission Experiment
- Voice and Music Transmission Tests

The following is a brief account of the purpose of each test together with the results obtained. A detailed account of the experiment results are provided in the Echo II Project Final Report.

EXPERIMENT RESULTS

Signal Level Measurement Test

This test provides data for determining the scattering cross section area of the satellite, the distribution of amplitude fading, the autocorrelation function and the relative amplitude spectrum of received power. The data consists of recordings of signal level versus time both on magnetic tape and on strip charts. Figure 2 is a typical record (bistatic case) of the received signal strength versus time as received at the NRL facility. As the figure shows, the peak signal level is about -100 dbm. Average fluctuations in the signal are on the order of ±5 db with short deep fades of up to 20 db occurring frequently. These fades (scintillations) are probably due to irregularities (wrinkles) in the satellite's surface caused by the satellite spin. Details regarding the satellite spin and its effect were included in the Echo II Post Launch Analysis Final Report[2].

Figure 3 shows some samples (monostatic case) of the character of the signal received by the Collins radar on Echo II pass number 3483.

These are quite similar to the signal recorded by NRL. Figure 4, recorded by the Collins radar, shows an example of an unusual signal recording that occurred occasionally at all stations. During a portion of this pass, as shown by

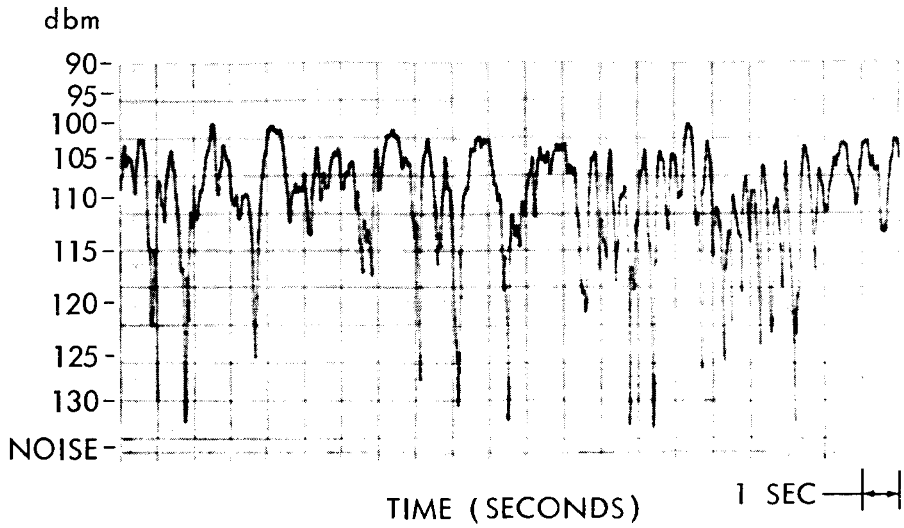


Figure 2. Signal Strength Oscillograph for Echo II recorded at NRL

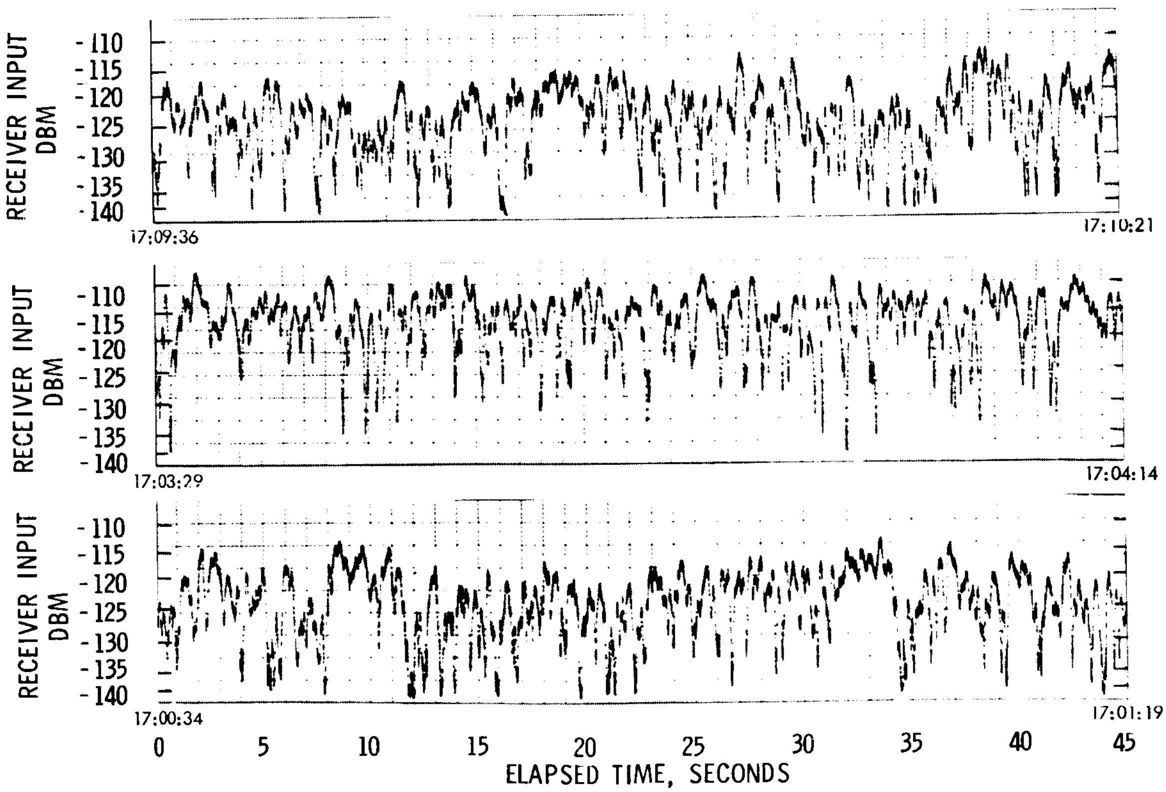


Figure 3. Portions of Signal Trace for Pass 3483 – Echo II, recorded at Dallas

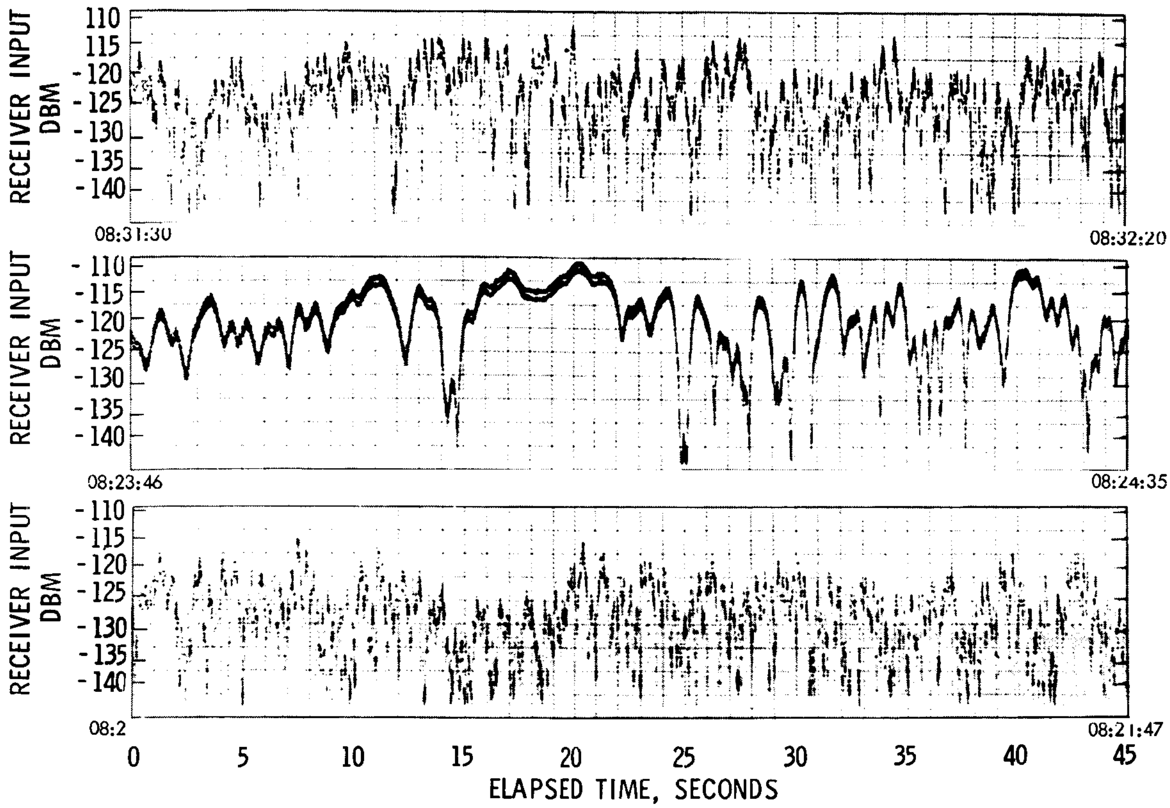


Figure 4. Portions of Signal Trace for Pass 3001 – Echo II, recorded at Dallas

the middle trace, the signal level fluctuations have slowed down and have virtually disappeared. This phenomenon is thought to be caused by the coincidence of the reflection point with the pole of the satellite's axis of rotation.

Average Scattering Cross Section

The effective or apparent scattering cross section of an object can be defined as the cross section (πr^2) of a perfectly reflecting sphere which would give the same strength of reflection as does the object. The effective scattering cross section of a passive satellite such as Echo is important in that it provides a measure of its efficiency. In addition, an indication of the structural shape and surface characteristics can be obtained.

To determine the cross section, the instantaneous signal level at each station was recorded on magnetic tape as a function of time. In the processing of the Collins and NRL data, these magnetic tapes were then linearized through an analog computer, resulting in a linear analog of received power. These analog data were averaged over one-eighth of a second and digitized each quarter of a second, then combined with the post facto range data, in a computer, from which the equivalent satellite cross section was obtained.

Individual cross section data points were then averaged in order to provide an average equivalent cross section for each pass whose data was processed. Figure 5 shows the plots of these averages over the eleven month test period. A measured cross section average of about 1060 square meters (30.2 db above one square meter) was obtained, as compared to the theoretical cross section of 1320 square meters (31.2 db above one square meter) for a perfect 135 foot diameter sphere. The averages for the individual passes show some scatter about the overall average, but when the span of time and the many variables to be controlled are taken into consideration, this scatter of approximately ±1 db is quite good. Five of the 23 passes are excluded from the 1060 square meter average because tracking problems existed at Collins or NRL during these passes. However, the inclusion of these passes would lower the overall average cross section by less than 1/2 db.

For comparison purposes, several Echo I passes were tracked and the data reduced. The results indicate a cross section average of approximately 3 db less than that for Echo II. This is approximately equivalent to the ratio of their theoretical cross sectional areas.

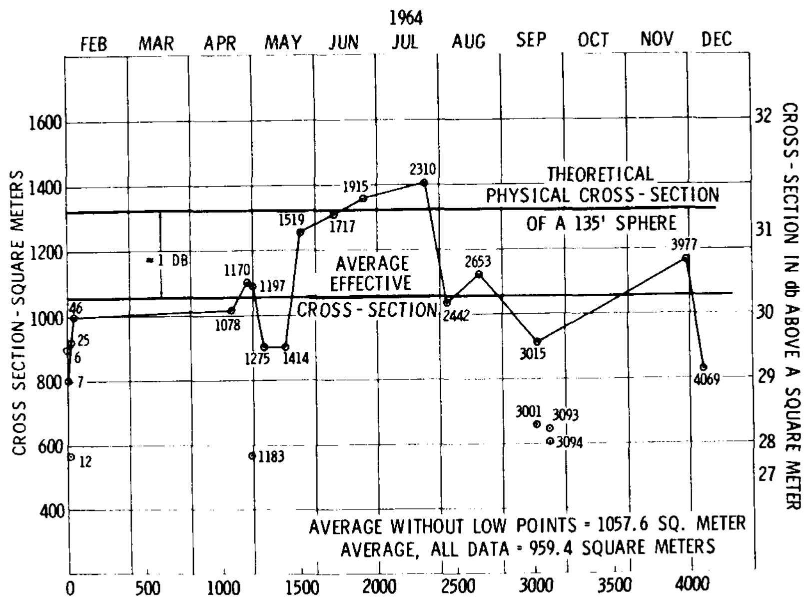


Figure 5. Echo II Average Cross Section

A probability density histogram, as shown in Figure 6, was used in the statistical analysis of the cross sectional area data. This histogram shows the probability that any particular value of cross section will occur. The highest percentage of samples in this pass occurred, at about 500 square meters (27 db). The mean (average) value of cross section was calculated to be 1110 square meters (30.5 db).

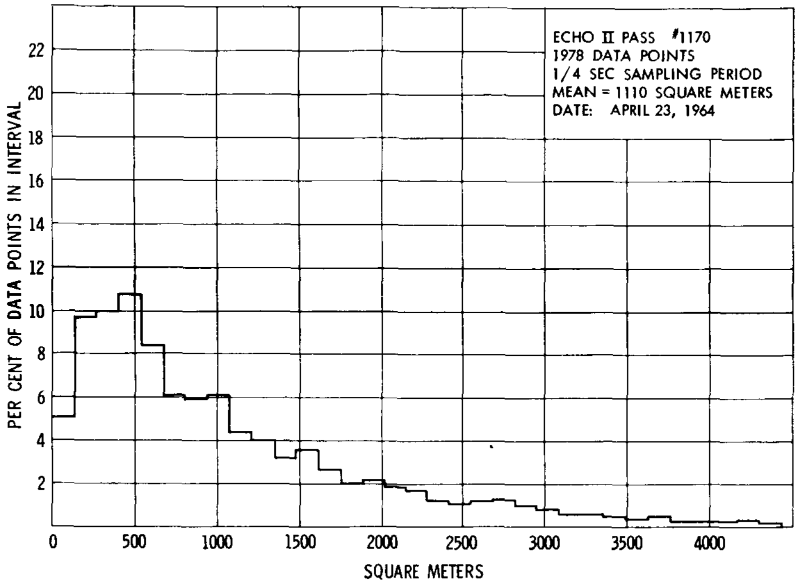


Figure 6. Density Histogram – Pass #1170

When the probability density, Figure 6, is integrated, a useful form of statistical information is obtained for designers and possible users of these types of communication systems. This is shown in Figure 7 and is called the cumulative distribution. This figure shows the percentage of time that any particular value of cross section will be exceeded. The median, or 50 percent value, is approximately 29 db above a square meter. The fading range can also be determined when the percentage of useful time is specified. In Figure 7, the fading range is 11 db if the upper 10 percent and the lower 10 percent of time is neglected; i. e., 10 percent to 90 percent levels. The data have been plotted so that Rayleigh distributed fading will be indicated by a straight line.

Rayleigh fading results when a signal has been reflected by a large number of randomly spaced objects whose physical dimensions are much greater than the

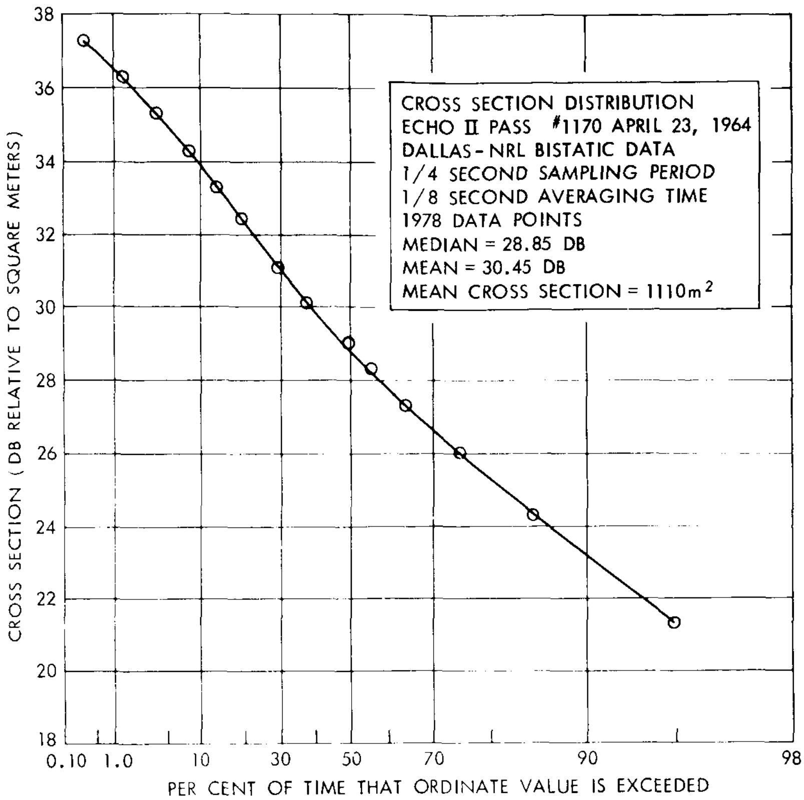


Figure 7. Cumulative Distribution

wavelength of the incident energy. The envelope variations are a result of phase interference between the reflected signal components arriving at the receiving point with randomly distributed relative phases. As applied to energy reflection from an Echo type satellite, the wrinkles of the satellite's surface probably act as a set of scattering centers to cause the received carrier envelope to be Rayleigh distributed. The fading of the signal very closely approximates a Rayleigh distribution.

Autocorrelation Function

Initial observation of signal information indicated an apparent periodicity in its fluctuations. In order to determine if periodicity did exist, an autocorrelation analysis of the reflected signals was made by OSU[3, 4].

Figure 8 is a typical sample of the results achieved at OSU on bistatic transmissions. The upper portion of the figure shows an expanded view of the autocorrelation function for a time delay of less than three seconds. Several curves are shown here, each of which is the autocorrelation calculated from a different 30 second segment of data. There is no consistent peak in the data. The bottom portion of the figure shows longer time delays. Once again, no significant periodicity can be seen in these results.

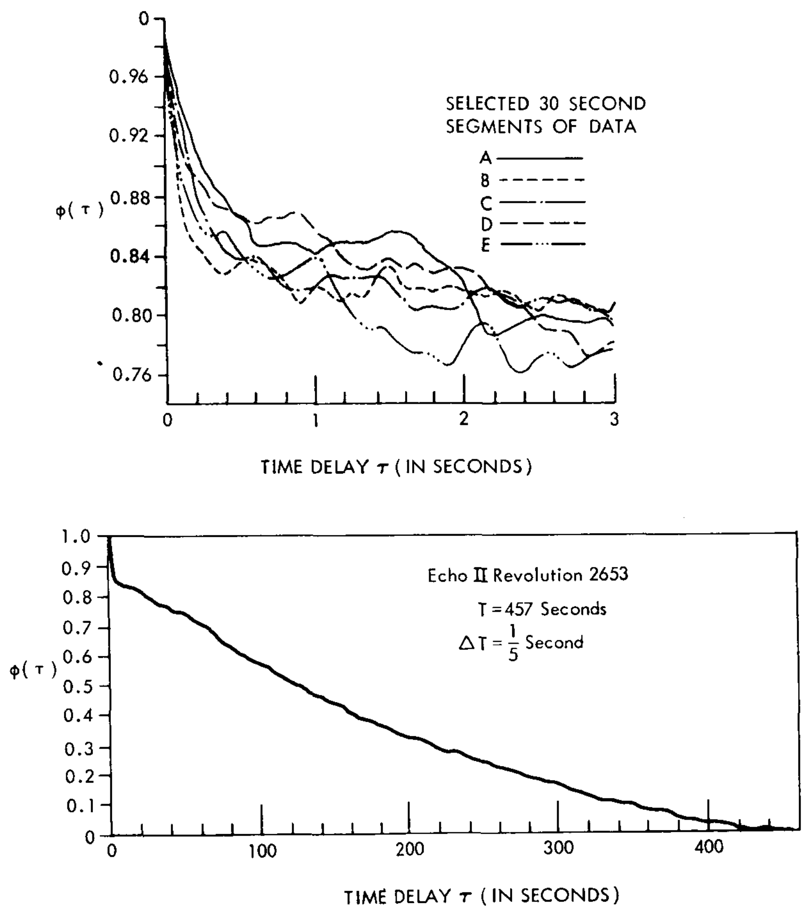


Figure 8. Autocorrelation Function of Echo II–Reflected Signals

An indication of periodic variations in the signal level, would mean that communication system responses would need to be adjusted accordingly. This would influence coding methods for some types of transmitted information. Such periodicity could also indicate the presence of gross satellite distortions.

Relative Amplitude Spectrum of Received Power

In order to determine the relative amounts of power contributed by various frequencies in the signal (scintillations), and to reveal any periodic variations present in the signal level, the relative amplitude spectrum of received power was determined from a number of passes. As explained above, any periodicity in the signal level would need to be taken into account in the design of communication system responses. Gross satellite distortion would also be indicated by signal level periodicity.

Figure 9 shows a composite of the spectra calculated on Echo II NRL data on several passes. As this figure shows, the relative amplitude spectra of received power have remained essentially the same throughout the experiment program (Jan. through Dec. 1964). Although not shown on this chart, the power at 0.1 cycle is in general 15 db down from the power at 0.001 cycle. These results indicate that virtually all of the power fluctuation occurred at frequencies below 3 or 4 cycles. Since inspection of the spectra does not show any pronounced peaks, no periodicity is indicated.

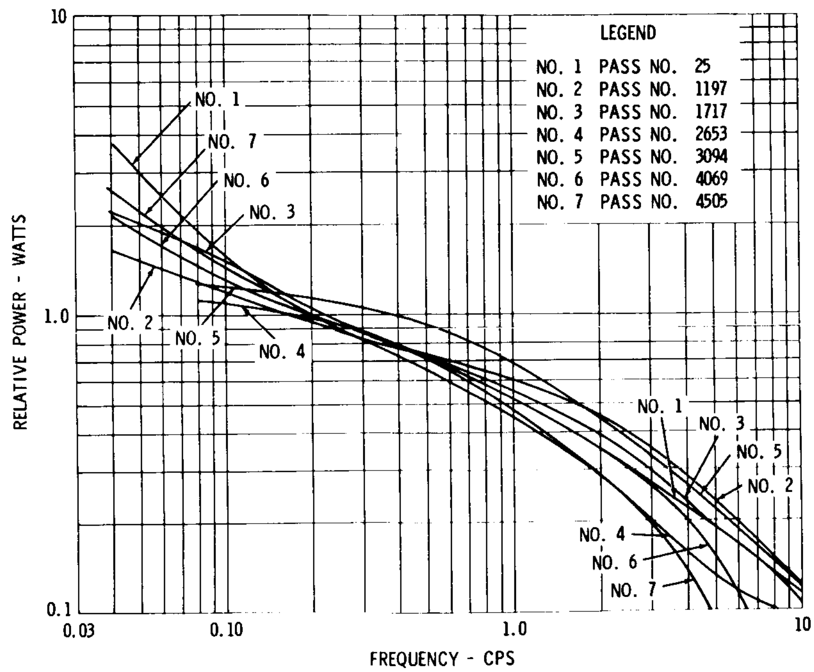


Figure 9. Relative Amplitude Spectrum of Received Power—Echo II

Coherent Band Width Measurements

Coherent bandwidth measurements were conducted on the Echo satellites to determine the following:

- The bandwidth capability, that is, the bandwidth over which there will be no degradation of the modulation due to selective fading.
- The frequency spacing and/or separation of receiving antennas necessary for good diversity operation.

The tests were conducted as follows: NRL simultaneously received and recorded two separate signals being transmitted by Collins. These signals were separated by 12 Mc, 70 Mc, and 190 Mc. The 12 Mc spacing was achieved by modulating the Collins transmitter with a 6 Mc modulation signal which resulted in sidebands 12 Mc apart. To provide the data for the 70 Mc spacing correlation test, NRL simultaneously received and recorded the 2190 Mc radar signal from Collins 28 foot antenna and the 2260 Mc CW signal from Collins 60 foot antenna. The 190 Mc spacing correlation was conducted similarly using 2190 Mc and 2380 Mc signals.

Table 1 shows some cross correlation results obtained on both Echo I and Echo II. These numbers represent the degree of correlation, or interdependence between the fading on two signals spaced as indicated. If the two signals faded exactly together, the value would be unity, indicating a high degree of coherent bandwidth for that frequency spacing; if the fading of the two signals was completely independent, the value would be zero; indicating no correlation thereby providing a good diversity capability at that separation.

Table 1

Cross Correlation Experiment Results

Spacing (Mc)	Echo II	Echo I
12	0.91	0.88
	0.90	
	0.84	
70	0.63	
	0.50	
190	0.44	0.39
	0.35	

On Echo II, the average correlation of approximately .90 at a 12 Mc spacing and an average correlation of about .56 at 70 Mc spacing indicates the coherent bandwidth of Echo II is in excess of 12 Mc but less than 70 Mc. Figure 10 shows the traces obtained on the 12 Mc test. The high degree of correlation between them is clearly evident. The low degree of correlation at the 190 Mc spacing (average of about .40) indicates that frequency diversity at this spacing would be successful.

Figure 10. Amplitude Correlation Measurement Echo II Pass 1533

Phase correlation measurements were made simultaneously with amplitude correlation measurements at a spacing of 12 Mc. Equipment limitations made it impossible to make these measurements at 70 Mc and 190 Mc spacings. The phase correlation at a 12 Mc frequency separation was determined to be high and to compare favorably with the amplitude correlation results obtained at this frequency spacing.

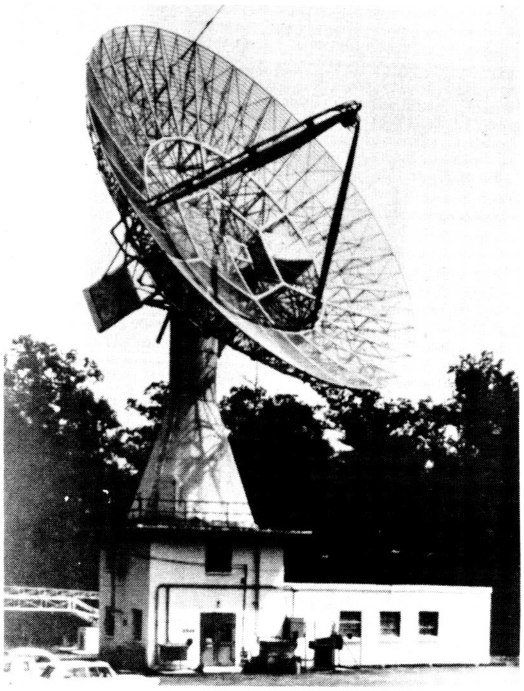
Since the amplitude correlation measurements involved space diversity at the Collin's facility as well as frequency diversity, an additional measurement was conducted to determine the contribution of the space diversity effect. In this test, NRL transmitted at 2380 Mc with Collins receiving on their two antennas which were separated by approximately one-half mile. The data from this test showed a correlation of 0.78. Since this is quite high, it can be concluded that space diversity had a limited effect on the frequency diversity measurements and that space diversity would not be very successful with this spacing.

It is noted that these measurements conducted on the Echo I satellite gave results similar to those obtained on Echo II.

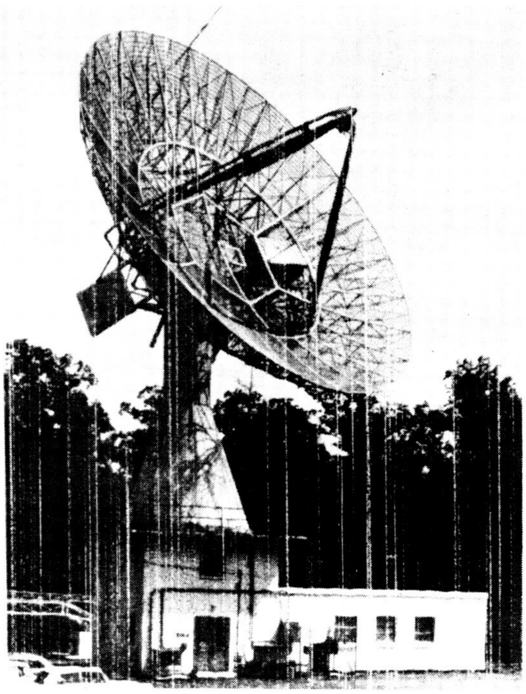
Facsimile Transmission

Facsimile experiments were conducted to determine the performance of the Echo satellite circuits on facsimile transmission.

On the left of Figure 11 is a picture of the NRL station reproduced directly from the master magnetic tape and on the right is the picture after it was transmitted by speeded up facsimile over Echo II and received at NRL. The streaks in the received picture are caused by the quick deep fades shown in Figure 2.



COPY OF PHOTOGRAPH
TRANSMITTED BY FACSIMILE



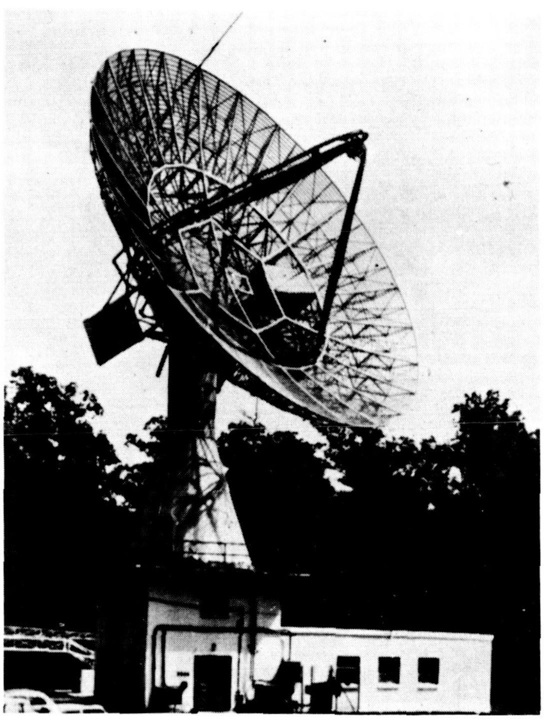
COPY OF PHOTOGRAPH
RECEIVED BY FACSIMILE
VIA ECHO II

Figure 11

Figure 12 shows the original picture again on the left and on the right is the picture received via Echo I. The streaks are longer and more frequent in this picture received via Echo I. For this experiment, the facsimile signals were recorded on magnetic tape along with a low-level, 1000 cycle tone for recorder speed control and doppler correction. The experiment was performed by playing this tape into the transmitter at four times the recording speed. The transmission utilized frequency modulation of the facsimile information onto the carrier and the reception was with a standard frequency modulation discriminator. Peak deviation used was ±15 kc.

Voice and Music Transmission

A number of audio tests were conducted including the transmission of voice and music using FM with modulation frequencies of 30 to 15,000 cycles with a frequency deviation of ±15 kcs from the Collins station to the NRL station. Good



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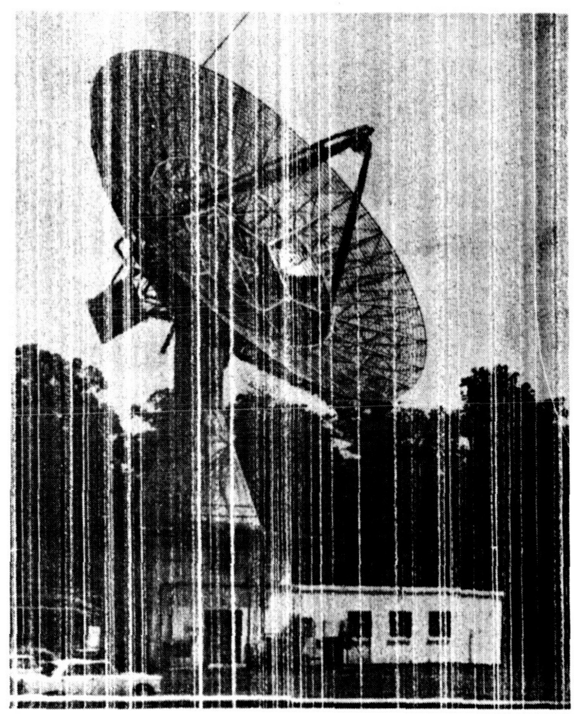

COPY OF PHOTOGRAPH
RECEIVED BY FACSIMILE
VIA ECHO I

Figure 12

results were obtained in these experiments. Except for an occasional burst of noise during deep fading, the transmission was clear and virtually noise free and at no time was selective fading evident.

SUMMARY AND CONCLUSIONS

The experiment results indicate that there was no apparent change in the scattering cross section of the satellite from the time it was first observed on its fifth orbit by experimenters until the first phase of the experiments were completed approximately one year after launch. This, in conjunction with the bistatic experimental data indicates that the satellite was essentially spherical in shape, with no gross surface distortions. The actual average scattering cross section obtained was 30.2 db. This compares favorably with the theoretical cross section for perfect 135 foot diameter sphere of 31.2 db.

The experimental results indicate a satellite bandwidth capability in excess of 12 Mcs. Amplitude correlation measurements indicate that frequency diversity techniques would be quite effective at a frequency separation of approximately 190 Mcs or greater.

Good results were obtained from facsimile, voice, and music experiments. Except for occasional short bursts of noise during fading, the transmission was clear and virtually noise free. There was no evidence of selective fading.

The demonstrated capability of transmitting the equivalent of four voice channels over a distance of 1175 statute miles, with a power of 800 watts; 60 foot diameter antennas; a receiving system with a noise temperature of about 550°K; and non-optimum modulation and demodulation techniques, indicates that this type of system would make a practical long distance communication circuit.

Limited tests were performed with Echo I during this experiment program. The results of these tests indicate that Echo II is superior to Echo I as a communication satellite. However, the Echo I experiment results are remarkably good in view of its original configuration and long lifetime in orbit and indicate that the satellite still offers a very useful communication medium.

It can be concluded that the Echo II satellite is a very satisfactory reflector for use in passive satellite communication systems.

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SUMMARY AND OVER-ALL RESULTS OF THE ECHO PROJECT

by H. L. Eaker, Goddard Space Flight Center

The Echo Project was established by the National Aeronautics and Space Administration (NASA) for the development of large spherical reflectors for use as communication satellites. The first step, Echo I, successfully confirmed the predictions of propagation theory regarding radio reflections from large spherical reflectors in orbit, and demonstrated the feasibility of communications via such satellites.

The Echo I satellite, launched August 12, 1960, weighed approximately 135 pounds, was 100 feet in diameter and was constructed of 1/2 mil mylar with a vapor deposited aluminum coating to provide an RF reflective surface. The satellite is still in orbit and continues to provide a very respectable reflector for passive communication purposes. However, after the loss of its internal pressure during its first two weeks in orbit, the satellite's efficiency as a communications medium began to decrease.

It therefore became apparent that a passive satellite of this nature, should be fabricated from a material such that the structure, once properly inflated, would maintain desirable spherical shape and surface characteristics even after the loss of its internal pressure. Project Echo II was established for this purpose. The Echo II satellite, 135 feet in diameter was launched from the Western Test Range on January 25, 1964. The satellite, constructed from a three layer laminate was designed to maintain its structural rigidity after loss of its internal pressure.

Extensive tests were conducted on satellite prototypes prior to fabrication of the flight article. However, their large size presented special problems for conducting the tests. Inflation Tests were conducted in a dirigible hangar at the Naval Air Station, Lakehurst, New Jersey, for the purpose of evaluating the structural, and RF backscattering characteristics of the sphere as a function of its internal pressure. The results of this test provided significant information regarding the satellite internal pressure necessary to achieve the desired rigidity characteristics.

In order that the satellite deployment and inflation technique could be properly evaluated prior to the orbital launch, vertical (ballistic) tests were conducted at the Eastern Test Range. The unique application of a television system designed to observe and record spacecraft operation was employed in the vertical tests as well as on the orbital launch. A very careful study of the project requirements versus available equipment and facilities was conducted prior to establishing the television system configuration. The system worked as planned. Excellent pictures of spacecraft operation were obtained during both the vertical test and the orbital launch. These are the first pictures obtained of the satellite being injected into orbit.

Two beacon telemetry systems were installed on the Echo II satellite to provide real time data regarding the satellite performance. In addition to tracking information, the system was designed to provide information regarding the satellite pressure and temperature. Excellent results have been obtained and the project has devised a method whereby a unique use of the collected telemetry data provides an accurate account of satellite spin.

Extensive communication experiments were conducted via the Echo II satellite during 1964 and to a limited extent with Echo I. These experiments were conducted in cooperation with the Naval Research Laboratory, Washington, D. C., Collins Radio Company, Dallas, Texas and the Ohio State University, Columbus, Ohio during 1964 in accordance with a Communication Experiment Plan prepared prior to launch. The primary objective of the Experiments was to determine the passive communications capability of the satellite, and in conjunction with radar experiments, to provide information about the shape and surface characteristics of the satellite as a function of time. Excellent results were obtained from these experiments and it can be concluded that the Echo II satellite provides a very satisfactory reflector for use in passive communication systems. Some experiments were also conducted on the Echo I satellite. While the results indicate Echo II is superior to Echo I as a communication satellite, they do indicate that Echo I has not deteriorated to the extent generally assumed and still offers a very useful communications medium.

During the radar and communication experiments conducted on both Echo I and Echo II, the need for a convenient and standardized means for the accurate calibration of certain radar and communication systems was apparent. An informal preliminary investigation indicates it is feasible that a calibration satellite could satisfy certain of these requirements. In the course of the investigation, it was learned that such a satellite, properly designed, could also be used in the calibration and checkout of certain other tracking instrumentation employed in support of our expanding space program.

The overall results of the Echo Passive Satellite Program are quite impressive. The very successful Echo I satellite demonstrated the feasibility of the launching into orbit of large space inflatable structures. The satellite further demonstrated the feasibility of communicating via such passive structures. The methods for solving some of the peculiar problems inherent in the design and testing of large inflatable structures of the Echo type was successfully accomplished in the Echo II program. Improvements in the design, fabrication, inflation and rigidization of structural materials were demonstrated. Static inflation and vertical test methods and procedures for the huge structures were established, providing an increase in spacecraft reliability. These test methods in conjunction with improved satellite instrumentation and a carefully planned satellite experimentation program provided an insight into the structural characteristics of the satellite over a period of time.

The comprehensive communications experiment program conducted with the Echo II satellite and to a somewhat lesser extent with Echo I, provided additional information regarding the passive communications capability of this type of inflatable structure. The Echo II satellite provided a means for conducting communications experiments between the United States and the Soviet Union. Lastly, in addition to their communication potential, both satellites have provided information leading to an improvement in orbital tracking methods; effects of the solar pressure and earth atmospheric drag on satellites; and on a regular basis provides an instrument whereby the U. S. Coast and Geodetic Survey can more accurately determine the geographical location of certain earth land masses.